On Network Structural and Temporal Encodings: A Space and Time Odyssey

Velitchko Filipov, Alessio Arleo, Markus Bögl, Silvia Miksch

Motivation

Graph structural & graph temporal encodings [1]

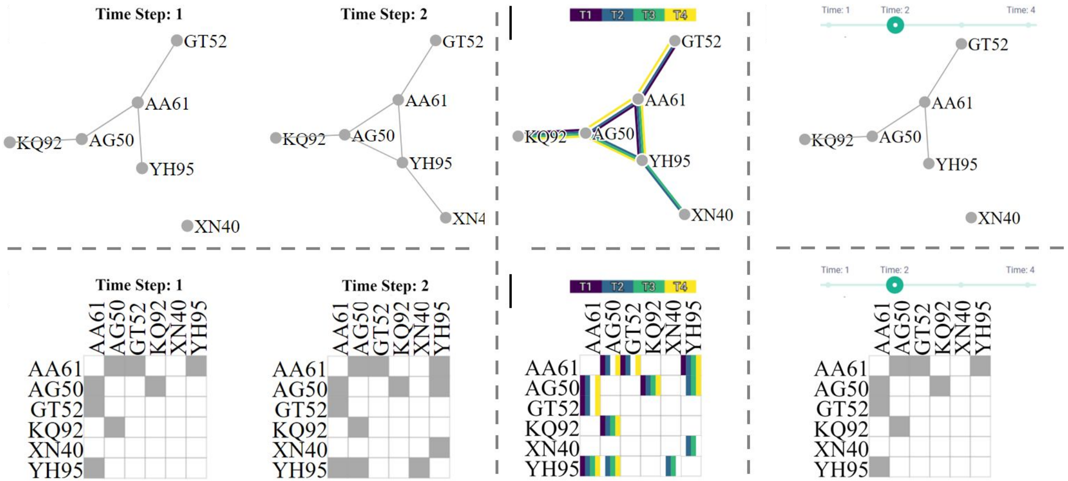
Static node-link and matrices [2, 3]
Dynamic node-link diagrams [4]
(Dynamic) Matrices under-investigated [5]

Comprehensive evaluation of dynamic network visualization
Qualitative & quantitative aspects

[1] Kerracher et al. "The Design Space of Temporal Graph Visualisation" (2014)
[2] Purchase "The Effects of Graph Layout" IEEE Computer Society (1998)
[3] Okoe et al. "Node-Link or Adjacency Matrices: Old Question New Insights" TVCG (2019)
[4] Archambault et al. "Animation, Small Multiples, and the Effect of Mental Map Preservation in Dynamic Graphs" TVCG (2011)
[5] Beck et al. "A Taxonomy and Survey of Dynamic Graph Visualization" (2017)

Contribution

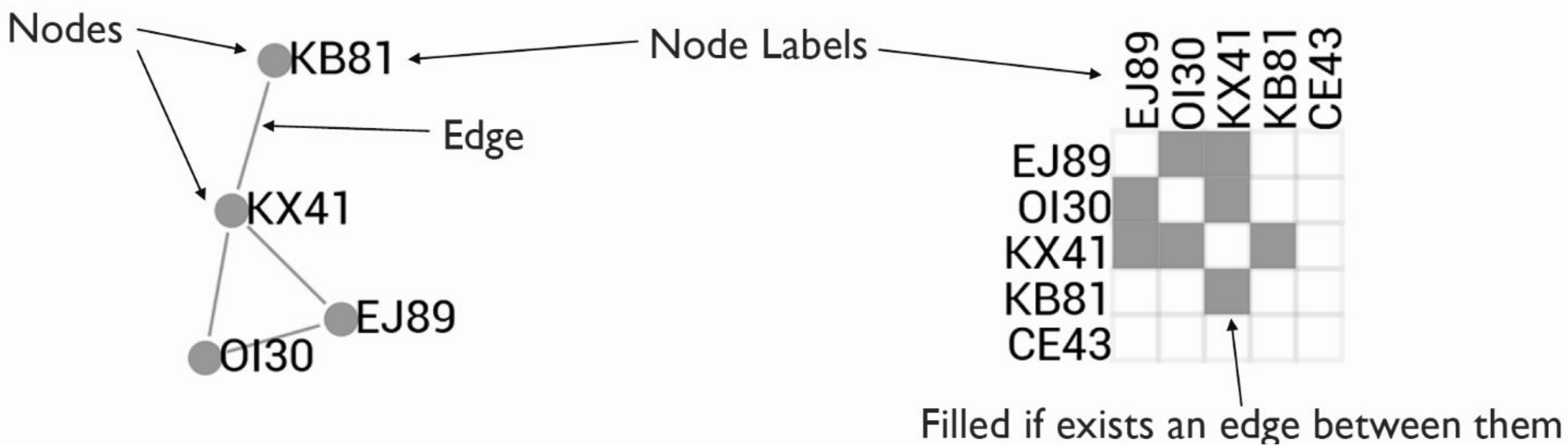
Comparatively evaluate design space of dynamic network visualization
Experimental studies (quantitative & qualitative)
Investigate performance under various conditions
Derive recommendations



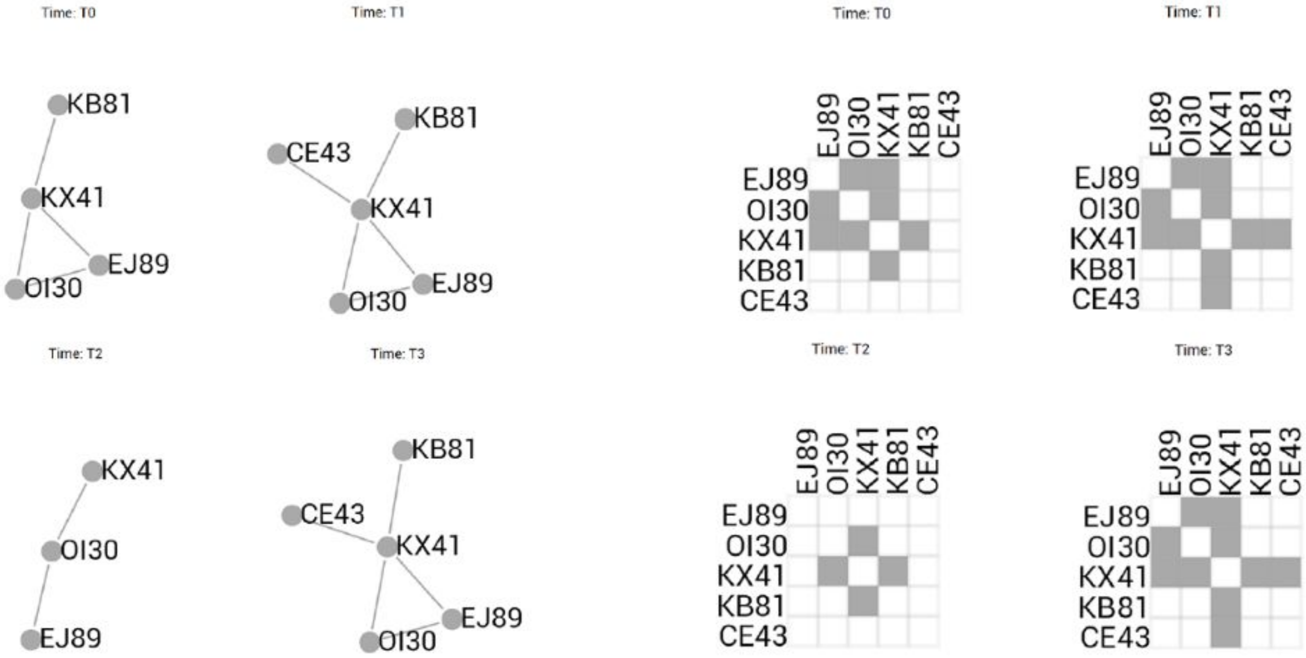
Structural Encoding

Node-Link Diagram

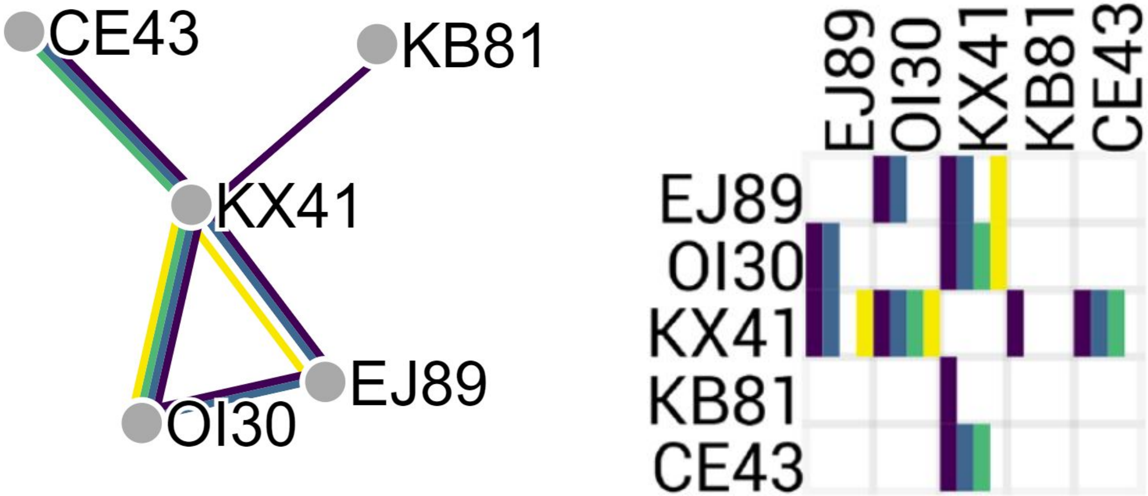
Adjacency Matrix



Temporal Encoding: Juxtaposition

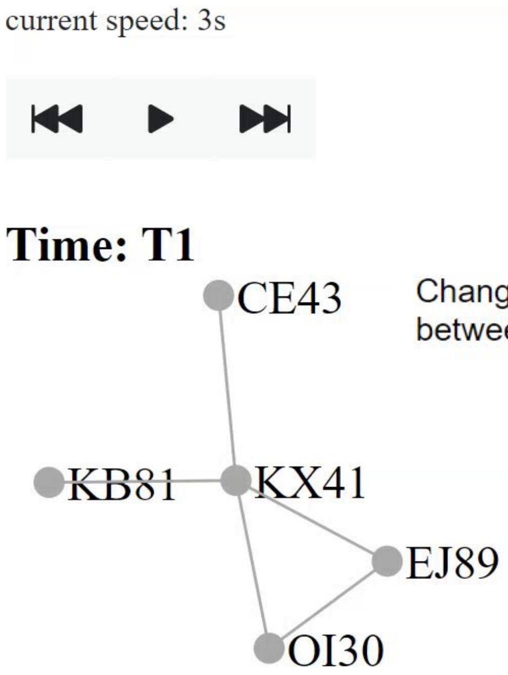


Temporal Encoding: Superimposition



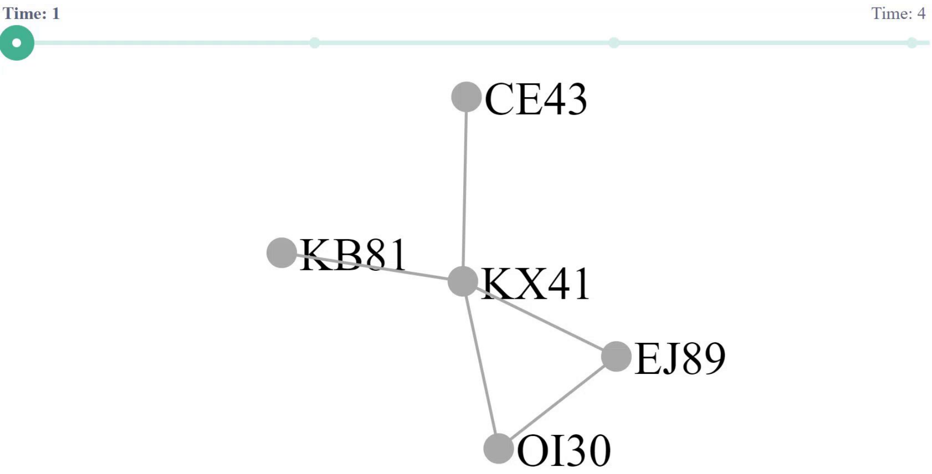
Each edge appears at a certain timestamp according to the legend

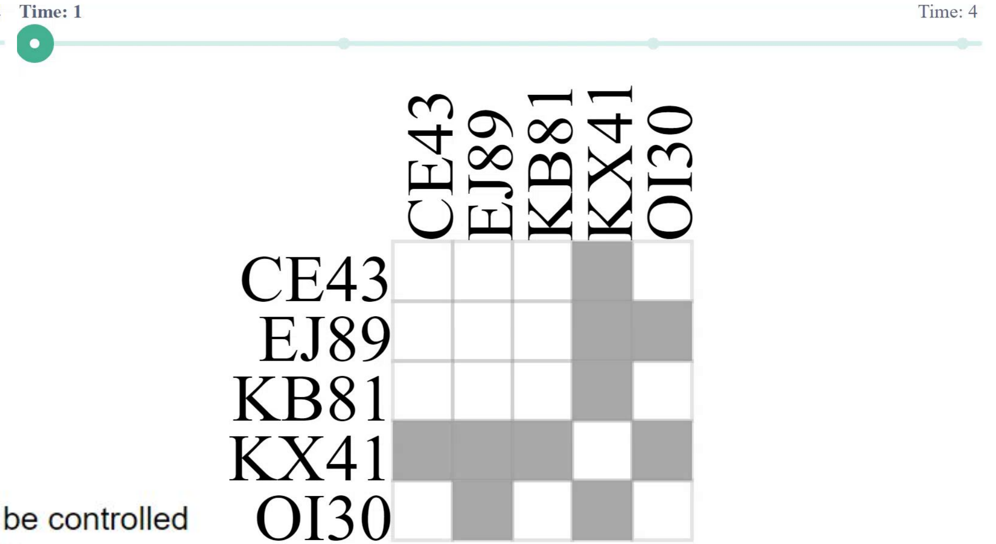
Temporal Encoding: Auto-Animation



Changes are animated between timestamps

Temporal Encoding: Animation w/ Controls





Changes can be controlled by a time slider

Studies

Study #1 (Quantitative)
User study 76 participants
Task-based questionnaire [5] using scale-free dynamic networks

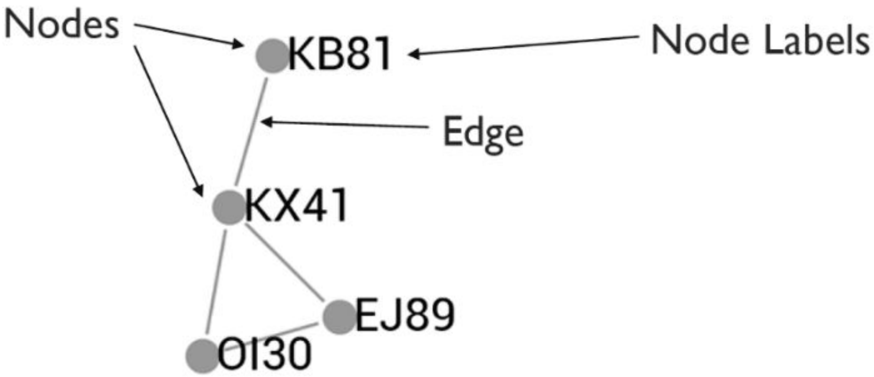
Study #2 (Qualitative)
Expert interviews 5 participants - ICE-T survey [6]
Open-ended analysis & exploration using InfoVis network [7]

[5] Ahn et al. "A Task Taxonomy for Network Evolution Analysis" TVCG (2014)
[6] Wall et al. "A Heuristic Approach to Value-Driven Evaluation of Visualizations" TVCG (2019)
[7] Isenberg et al. "vispubdata.org: A Metadata Collection about IEEE Visualization (VIS) Publications" TVCG (2017)

Outcomes Structural Encoding

Node-Link

- Best for overviews and understanding network topology
- Effective in combination with ANC
- Consistently favored for analysis and exploration



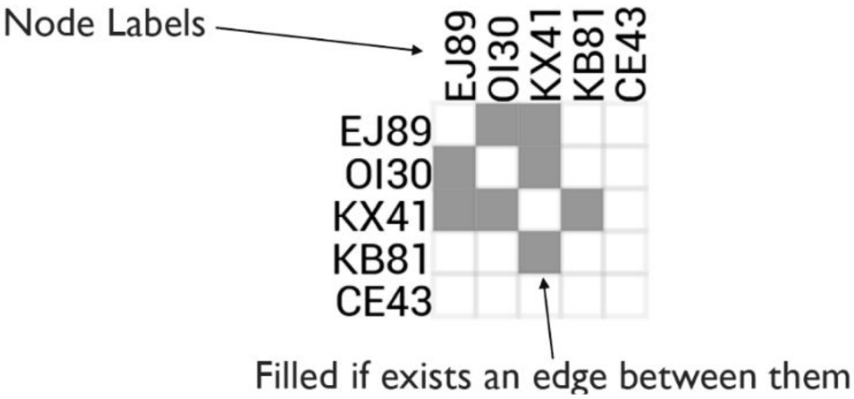
Outcomes Structural Encoding

Adjacency Matrix

Excel in accuracy for identifying specific connections

Challenges in managing large, complex networks

Effective for focused temporal analysis but less preferred

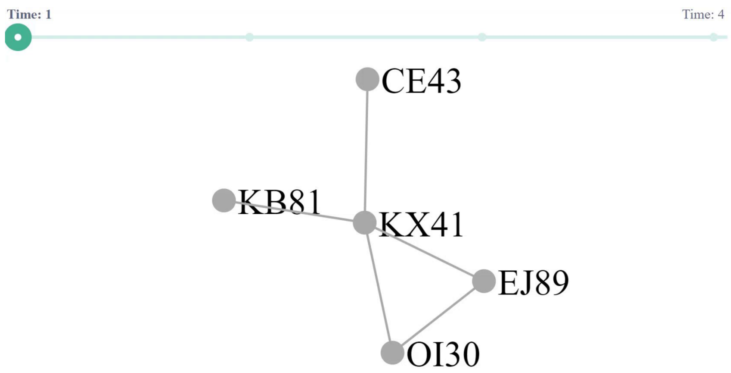


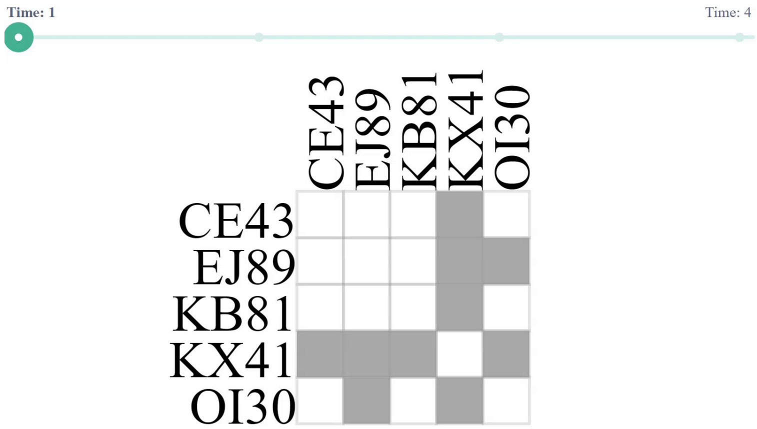
Outcomes Temporal Encoding

Animation w/ Controls

Most Preferred - precise control, supports detailed analysis

Particularly strong when paired with NL



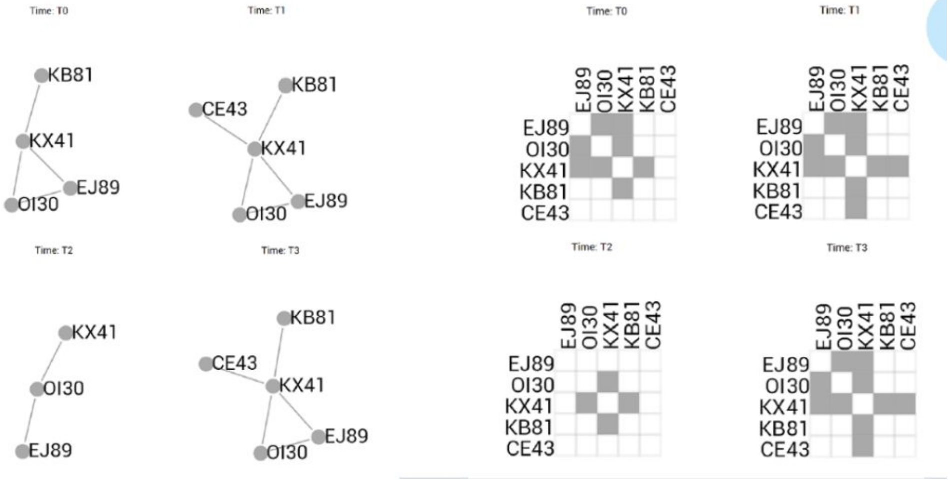


Outcomes Temporal Encoding

Juxtaposition

Useful for comparing specific time points

Less effective in larger, more complex scenarios

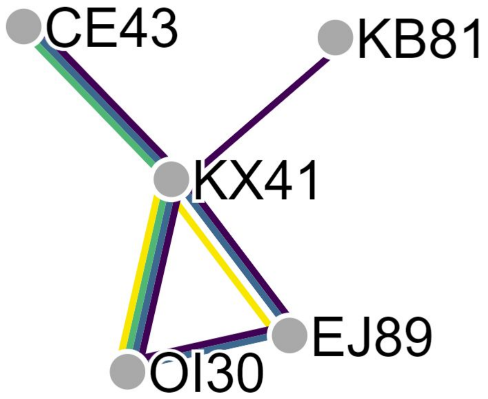


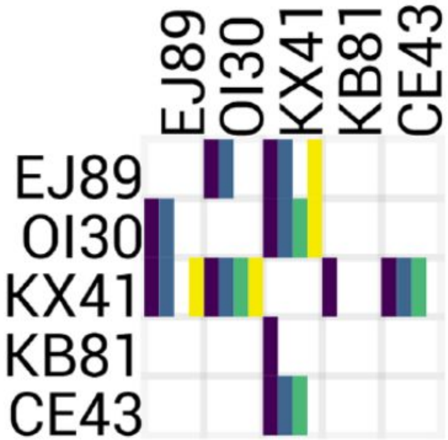
Outcomes Temporal Encoding

Superimposition

Useful for observing trends and persistent structures

Can become overwhelming in dense networks

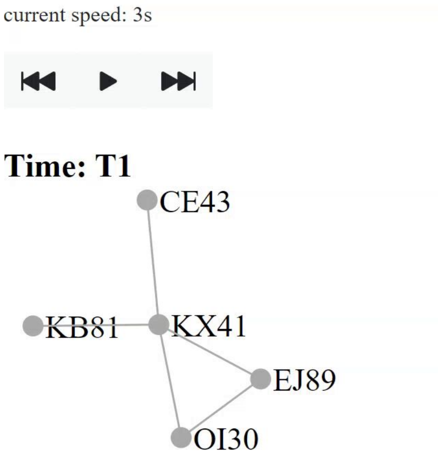


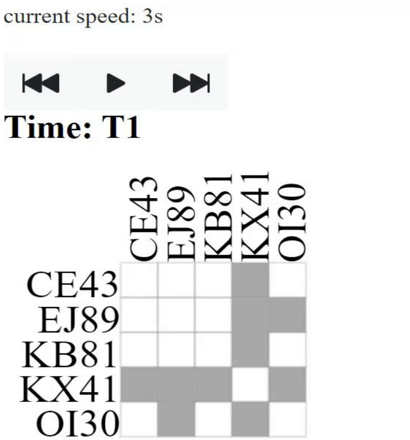


Outcomes Temporal Encoding

Auto Animation

- Good for understanding overall behavior
- Less effective for specific analysis





Summary - Key Findings

Juxtaposition

- Effective for overview of evolution
- Scalability issues beyond 8 timeslices

Animation w/ Controls

- Supports detailed analysis
- Increased cognitive load with comparing distant timeslices

Node-Link

- Easy to grasp, widely recognized
- Excel for understanding high-level network behavior

Adjacency Matrix

- Useful for low-level tasks
- Has a learning curve

VIS2024

(🔗to paper)

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📧velitchko.filipov@tuwien.ac.at

TU WIEN CVAST

BACKUP

Study #1

Study Design: Between subject (online)

Group A or B (without / with interactions)

76 total submissions completed

24 different graphs generated with networkX

$|V| \in [35, 45]$; $|E| \in [46, 71]$

48 Questions in total (2 entities) × (2 structural encodings) × (4 temporal encodings) × (3 tasks)

Study #2

Study Design: Expert Interviews
Heuristic Evaluation ICE-T [6]

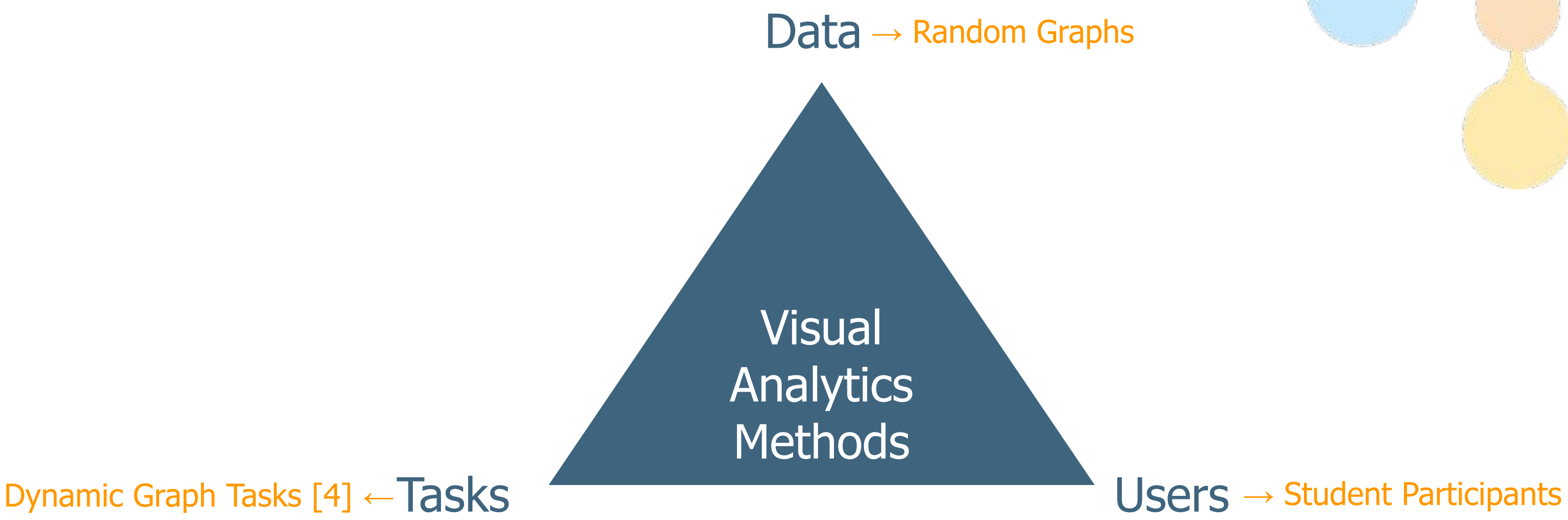
5 Network Visualization Experts

InfoVis Co-Authorship Network [5]

Open-ended Analysis Scenario
Post-interview Questionnaire (21 questions) + Thinking-aloud

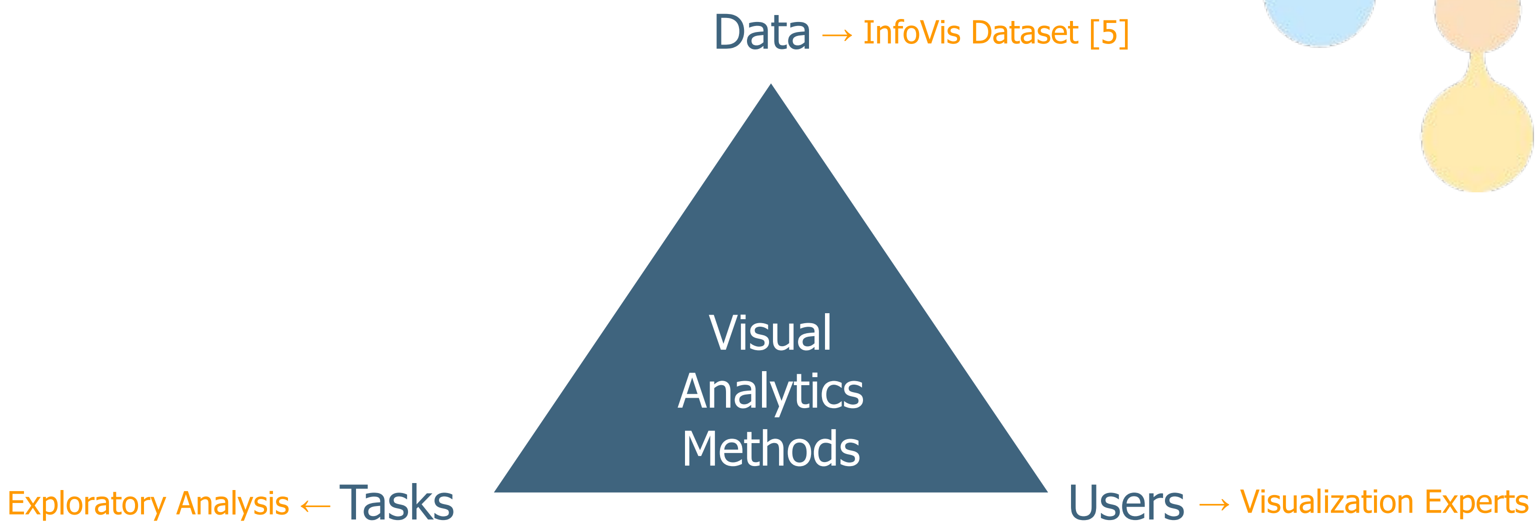
[5] Isenberg et al. "vispubdata.org: A Metadata Collection about IEEE Visualization (VIS) Publications" TVCG (2017)
[6] Wall et al. „A Heuristic Approach to Value-Driven Evaluation of Visualizations" TVCG (2019)

Study #1



[4] Ahn et al. "A Task Taxonomy for Network Evolution Analysis" TVCG (2014)

Study #2



[5] Isenberg et al. "vispubdata.org: A Metadata Collection about IEEE Visualization (VIS) Publications" TVCG (2017)

Study #1

Between subject (Group A-no interactions; Group B-interactions)

NL: Better for high-level tasks (overview, estimation, higher-level structures)

AM: Higher accuracy for low-level tasks (identifying specific nodes, edges, and timeslices)

Interaction: Significantly increases response times and improves accuracy

ANC: Most effective and preferred temporal encoding, outperforming others in task performance and user preference.

Study #1

Between subject (Group A-no interactions; Group B-interactions)

👍NL+JP lowest response time
👍NL+AN most balanced
👍Interactions improve accuracy (impact response times)

👎M not as good as NL
👎M+AN least preferred

Improvements

Interactions

- Highlighting

Sticky nodes

Matrix reordering

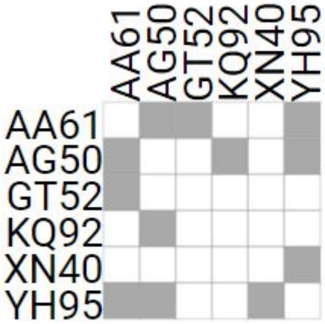
Animation controls

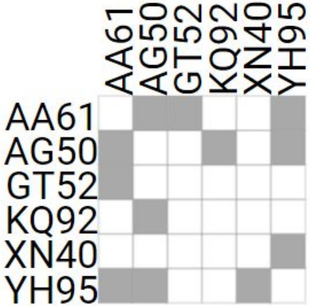
Visual encoding

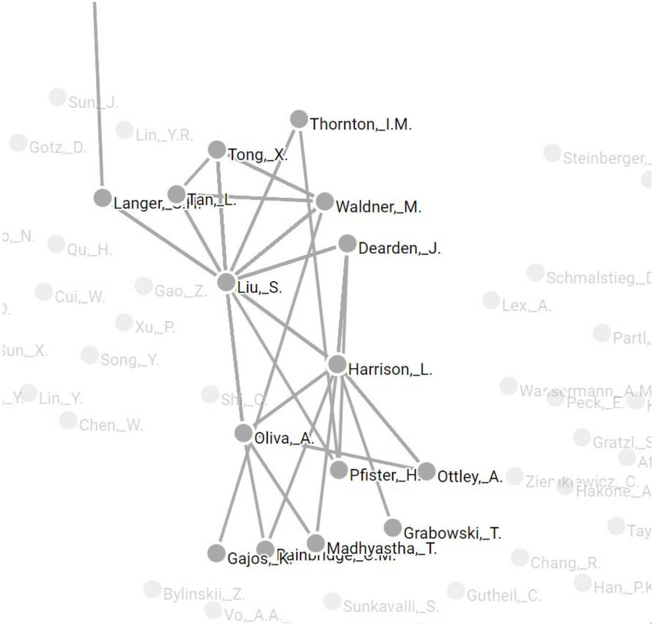
- Inactive elements, tooltips

Limitations

Graph size & number of timeslices







Study #2

ICE-T [6] - 5 network visualization experts on co-authorship network [5]

NL+ANC confirmed as the best-performing combination for complex, real-world network analysis tasks

M strong performance in controlled tasks, but scalability issues in more complex, realistic analysis contexts

NL+ANC useful for exploring network dynamics and identifying key patterns over time

JP ?

[5] Isenberg et al. "vispubdata.org: A Metadata Collection about IEEE Visualization (VIS) Publications" TVCG (2017)
[6] Wall et al. „A Heuristic Approach to Value-Driven Evaluation of Visualizations" TVCG (2019)

Study #2

ICE-T [6] - 5 network visualization experts on co-authorship network [5]

👍JP good for overview & ANC to investigate details
👍Interactions reordering & modifying layout
👍NL intuitive, ANC preferred

👎JP size limitations
👎ANC distant points in time
👎M bias

[5] Isenberg et al. "vispubdata.org: A Metadata Collection about IEEE Visualization (VIS) Publications" TVCG (2017)
[6] Wall et al. „A Heuristic Approach to Value-Driven Evaluation of Visualizations" TVCG (2019)

Summary

Augmenting network visualization with temporal information

Evaluating network visualizations for temporal graph tasks & insight-based analysis tasks

Recommendations for developers and designers