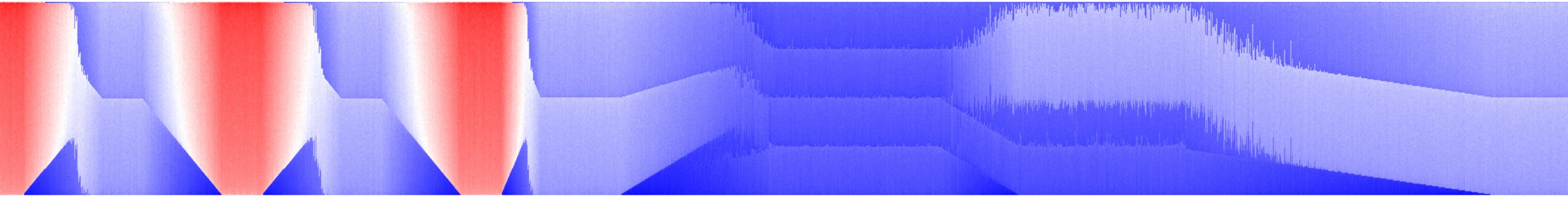


A Novel Ordering Strategy for 1D Pixel Visualization for Dynamic Networks

Bachelor Thesis Colloquium

Friederike Körte

Supervisor: Raphael Buchmüller
Data Analysis and Visualization
Department of Computer and Information Science, Faculty of Science
University of Konstanz, Germany, 23. July 2025

Research Objective

Introduction

Design + Implementation of NetworkRugs

Introduction of Priority-BFS node ordering strategy

Usecase driven evaluation:

- Does the ordering help detect **group structure changes**?
- What **patterns** can the visualization effectively reveal?

Why Visualize Dynamic Networks?

Motivation

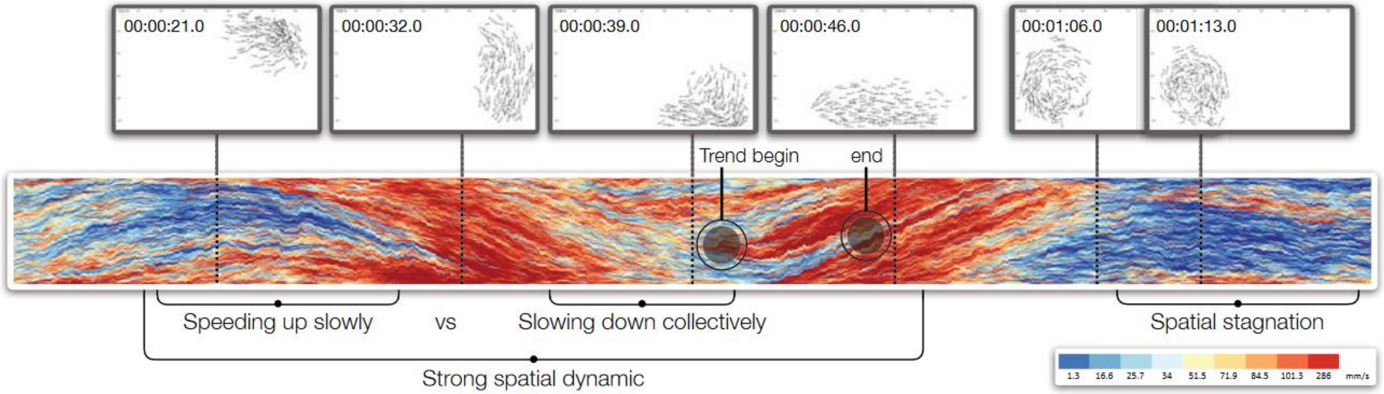
- **Dynamic networks** = systems where nodes/edges evolve

- Application Domain: Biology, Sociology, Art history

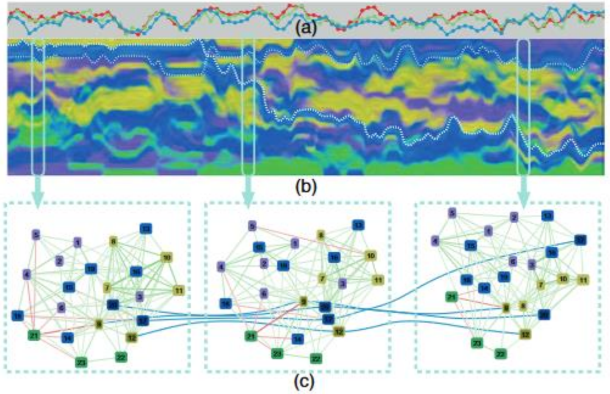
- Need: track group evolution over time

Pixel Visualization – Related Work

Motivation



[1] Buchmüller et al., 2019. MotionRugs: Visualizing Collective Trends in Space and Time.



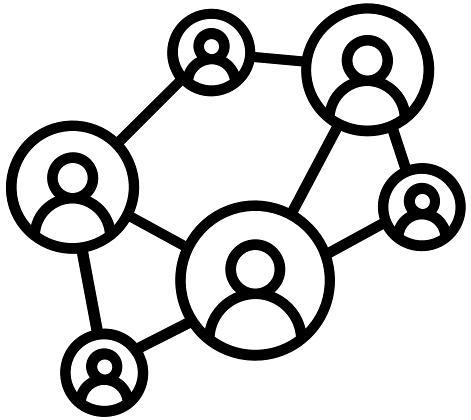
[2] Cui et al., 2014. Let It Flow: A Static Method for Exploring Dynamic Graphs.

Network Rugs

= compact visualization of network changes over time

What Patterns Do We Want to See?

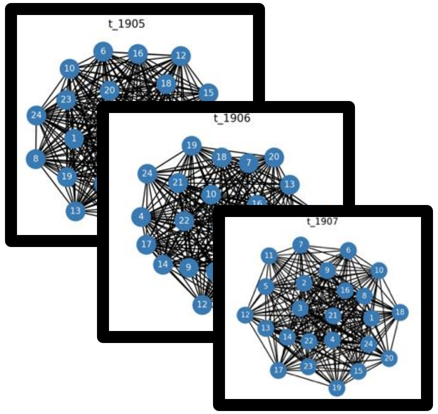
Background



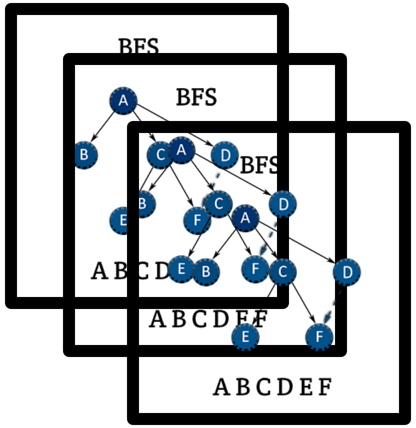
- Community-level: splits, merges, growth, shrinkage
- Node-level: role changes, mobility
- Global-level: stable vs. unstable phases, recurring events

The NetworkRug Technique

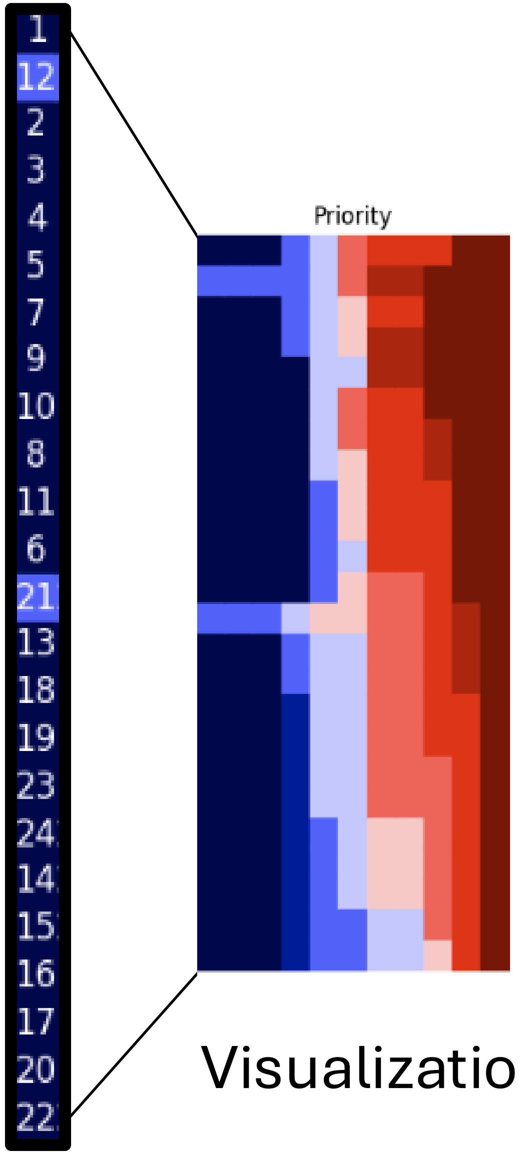
Approach



Graph Data



1D Ordering

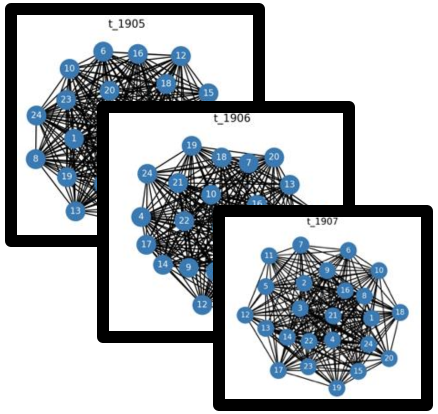


Visualization

① apply graph data structure to each time frame

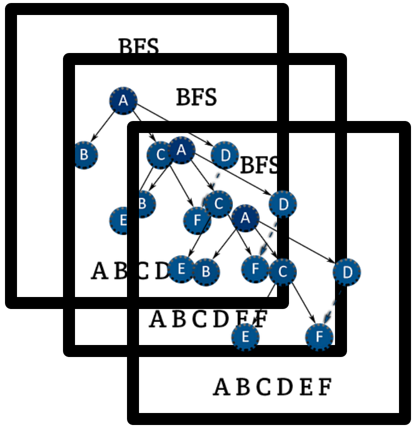
The NetworkRug Technique

Approach

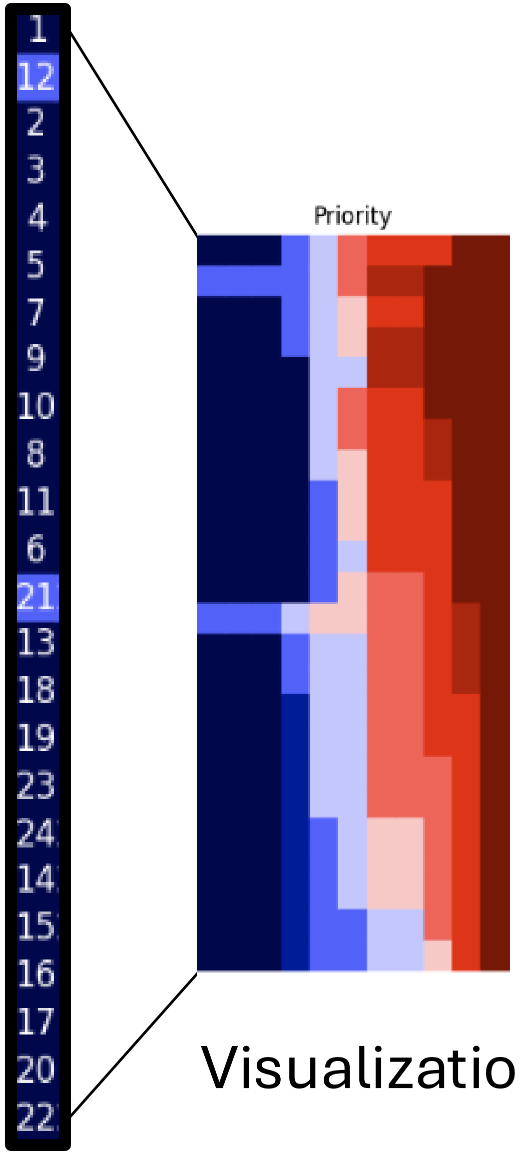


Graph Data

②



1D Ordering

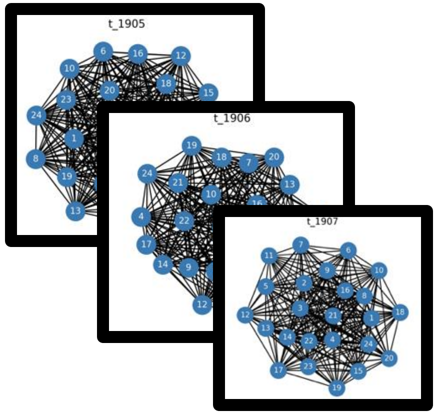


Visualization

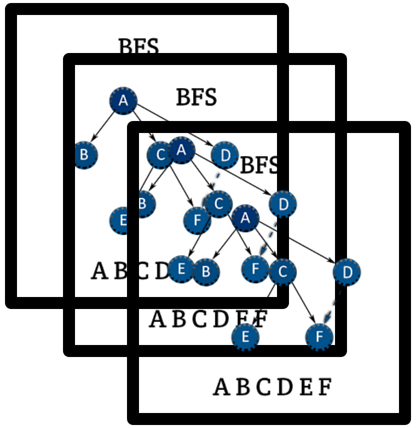
② apply ordering strategy per time frame

The NetworkRug Technique

Approach

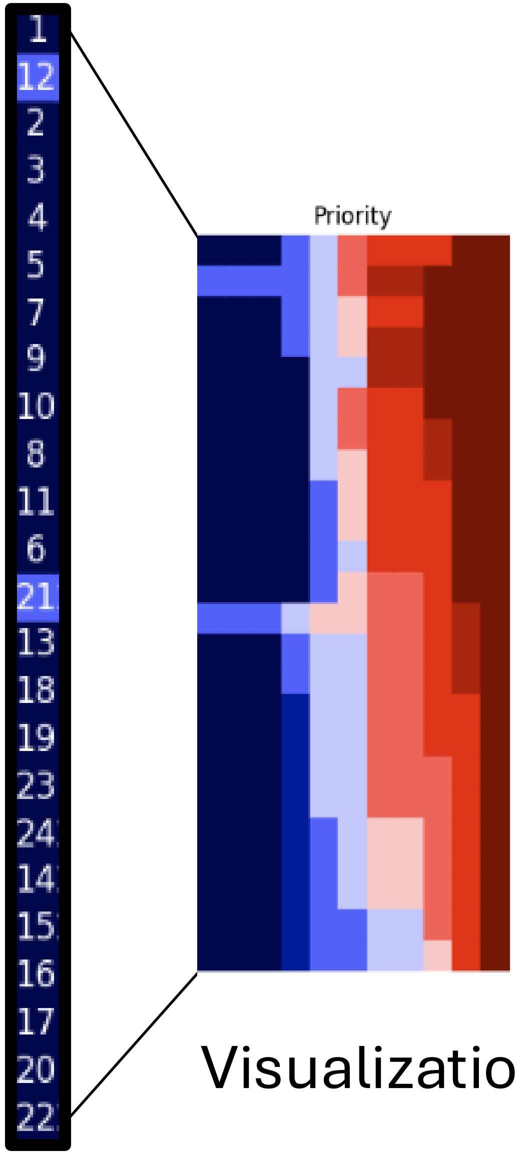


Graph Data



1D Ordering

3

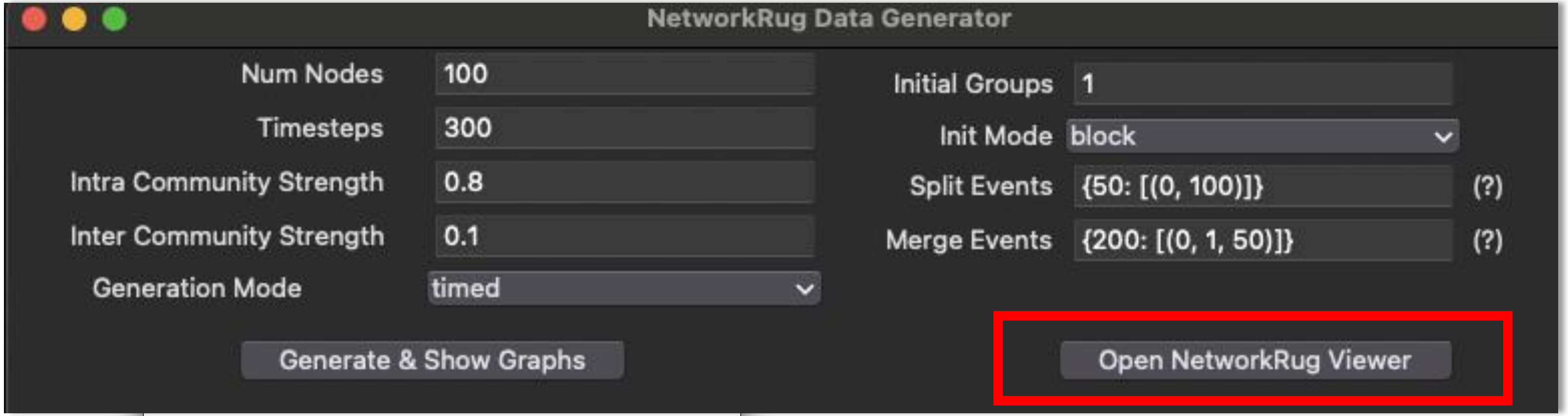


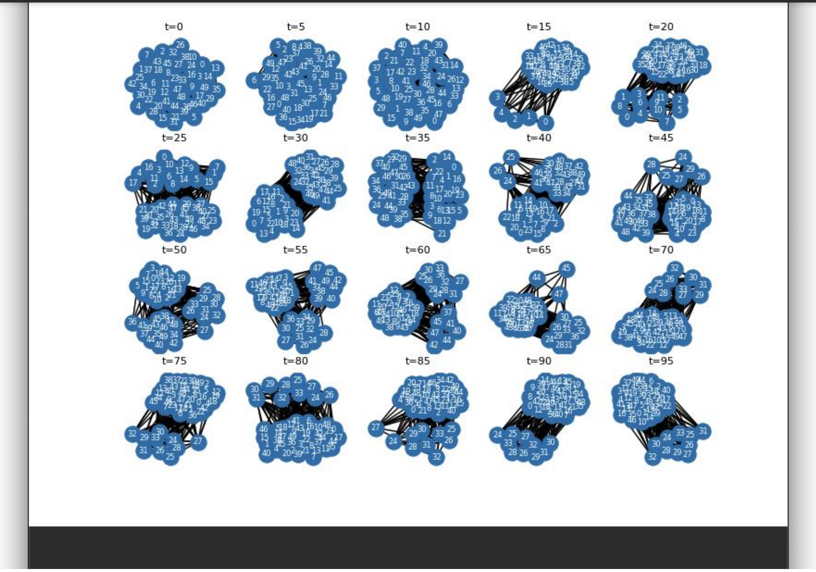
Visualization

3 sequential alignment of the slices on temporal axis and visualization *via* layout and color encoding

Test Environment + Interface

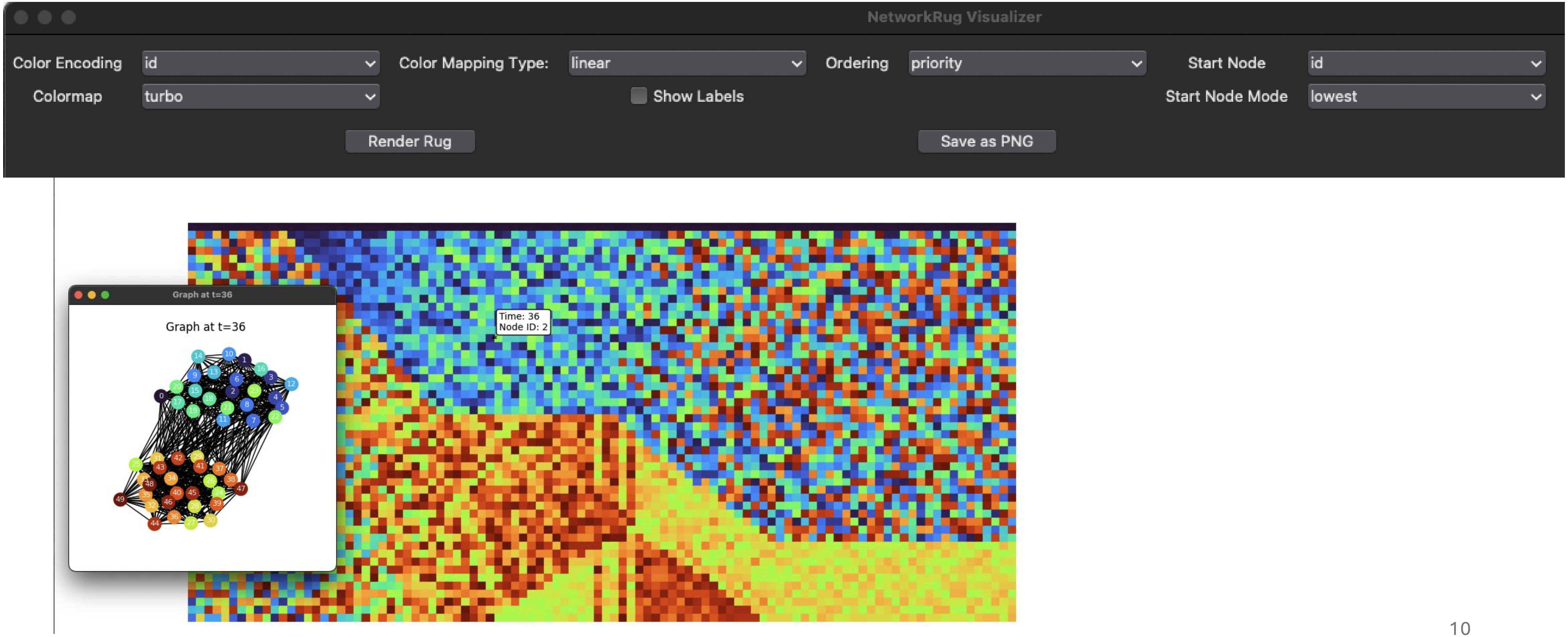
Approach





Test Environment + Interface

Approach

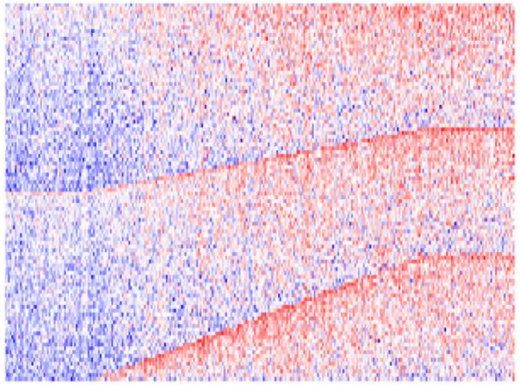


Parameters

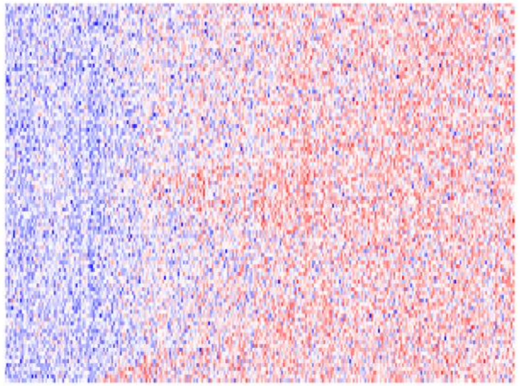
Visualization

Layout Decisions (Ordering + Positioning)

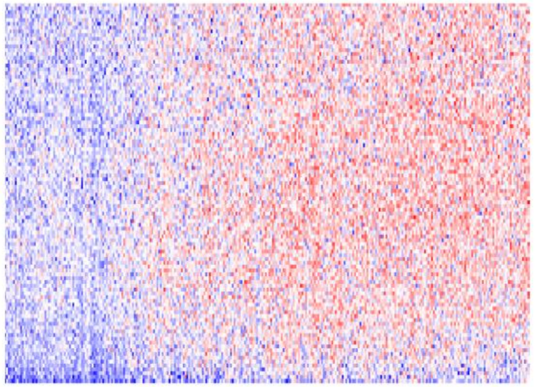
- Which ordering?



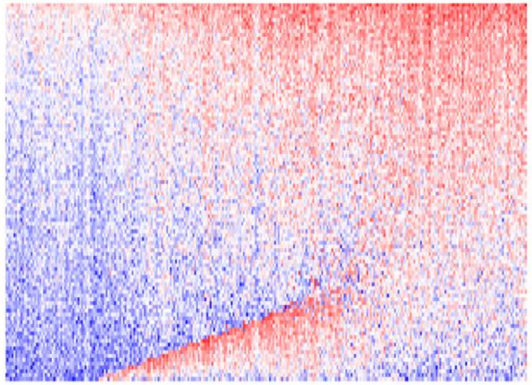
Priority



DFS



BFS



Metric (degree)

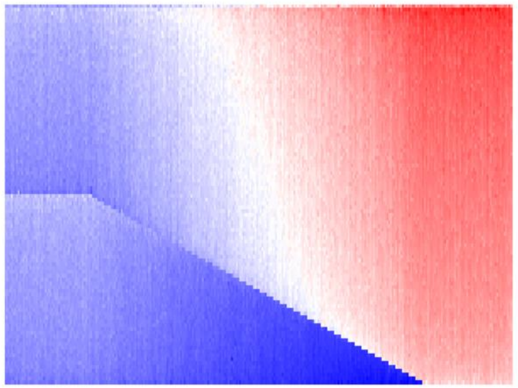
Parameters

Visualization

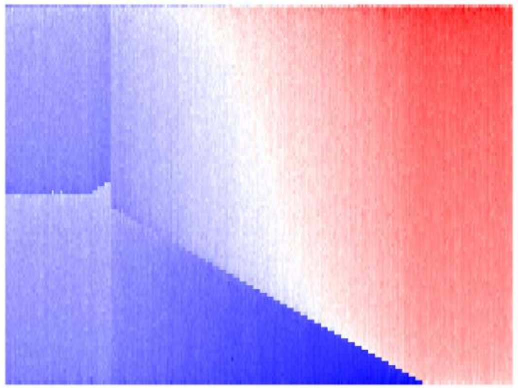
Degree Centrality: a node's direct connections
Closeness Centrality: average shortest path to other nodes
Betweenness Centrality: how often a node lies on the shortest path between others

Layout Decisions (Ordering + Positioning)

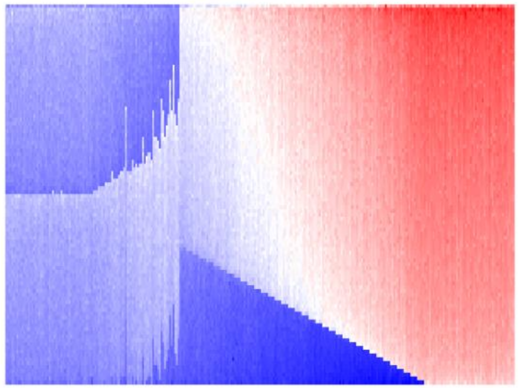
- Which ordering?
- Which start node?



Highest global Betweenness Centrality



Lowest Betweenness Centrality at t=0



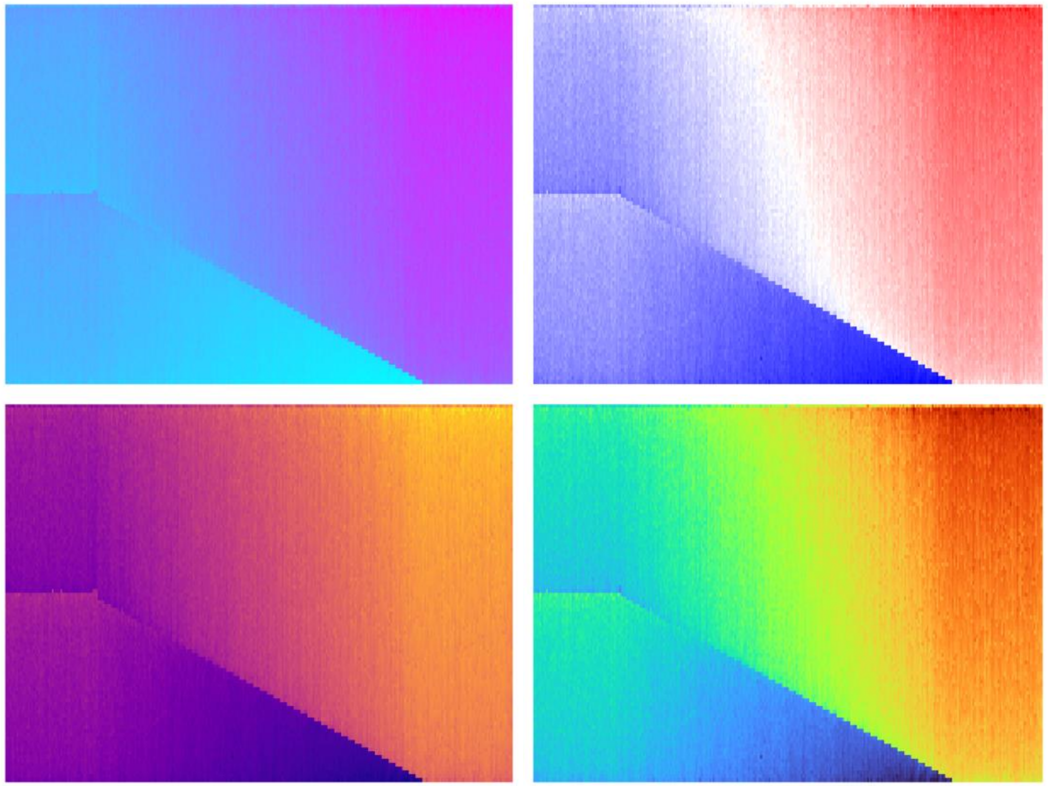
Highest Betweenness Centrality at t=0

Parameters

Visualization

Layout Decisions (Ordering + Positioning)

- Which ordering?
- Which start node?



Color Encoding

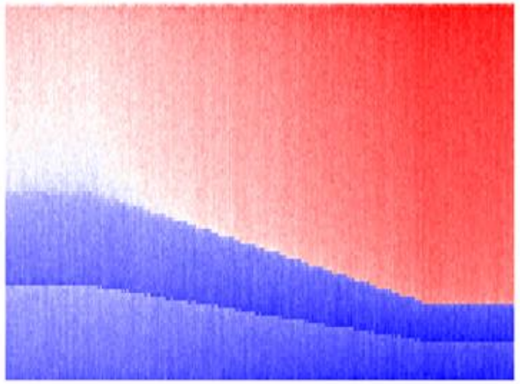
- Which colormap?

Parameters

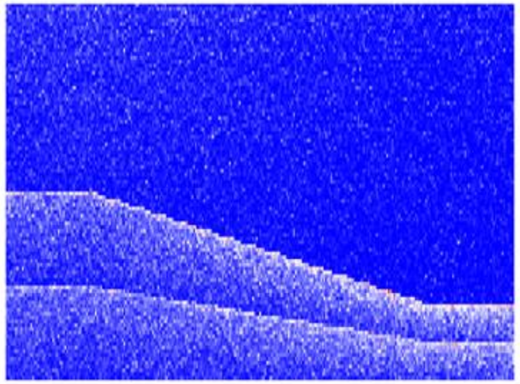
Visualization

Layout Decisions (Ordering + Positioning)

- Which ordering?
- Which start node?



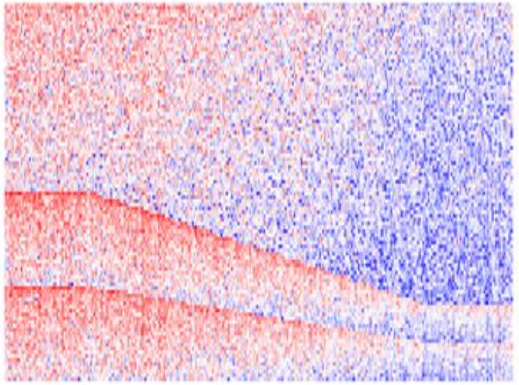
Degree Centrality (DC) - coloring



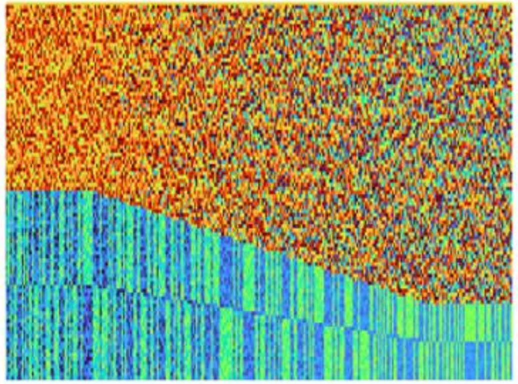
Betweenness Centrality (BC) - coloring

Color Encoding

- Which colormap?
- Which choice of centrality metric?



Closeness Centrality (CC) - coloring



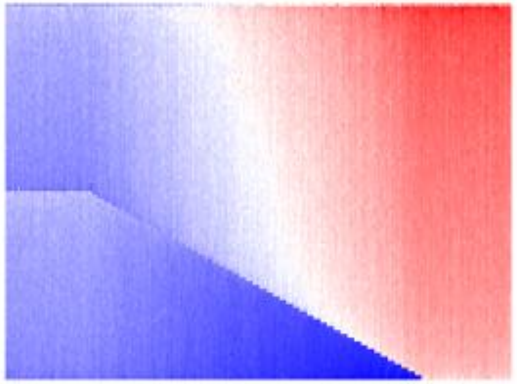
ID - coloring

Parameters

Visualization

Layout Decisions (Ordering + Positioning)

- Which ordering?
- Which start node?



Linear

Binned

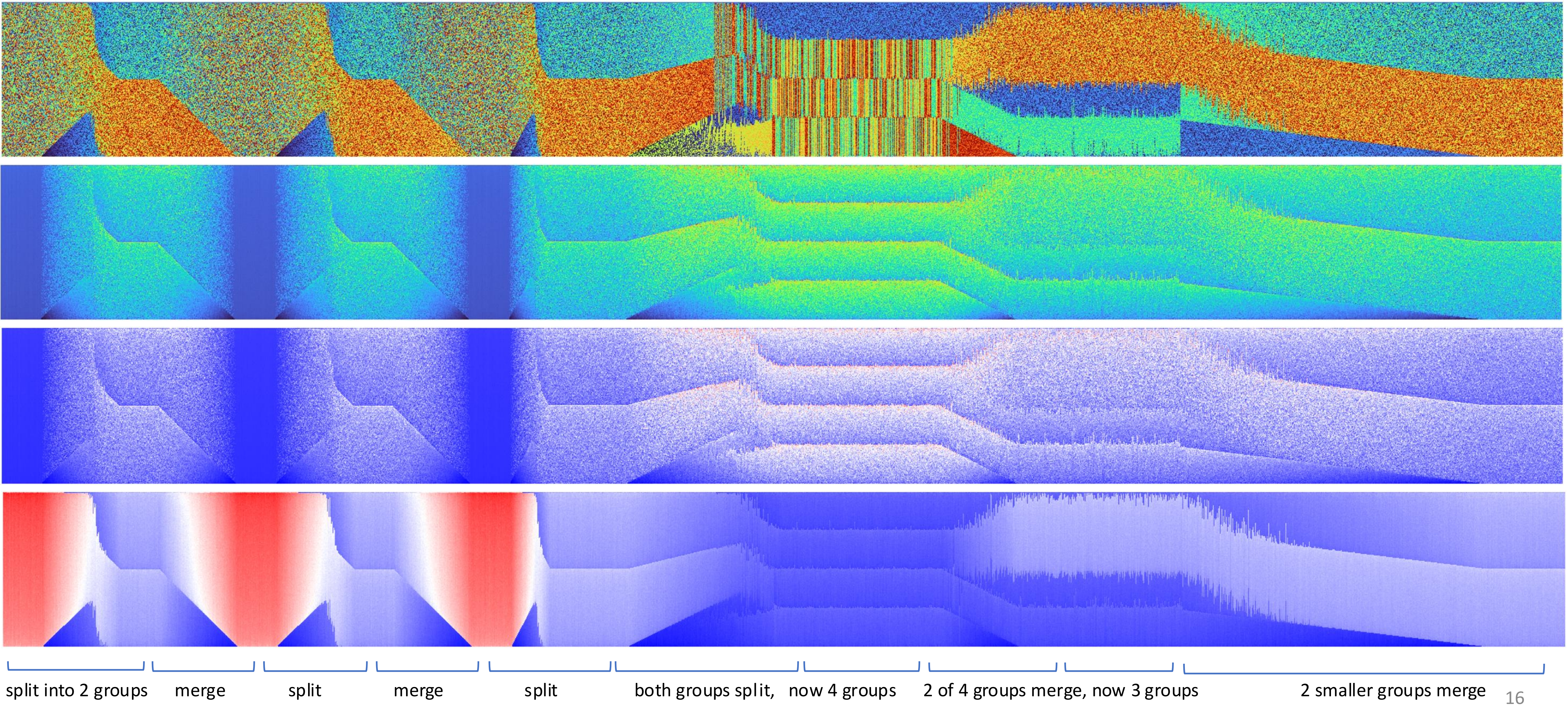
Color Encoding

- Which colormap?
- Which choice of centrality metric?
- Which color mapping type?

NetworkRug

Discussion + Results

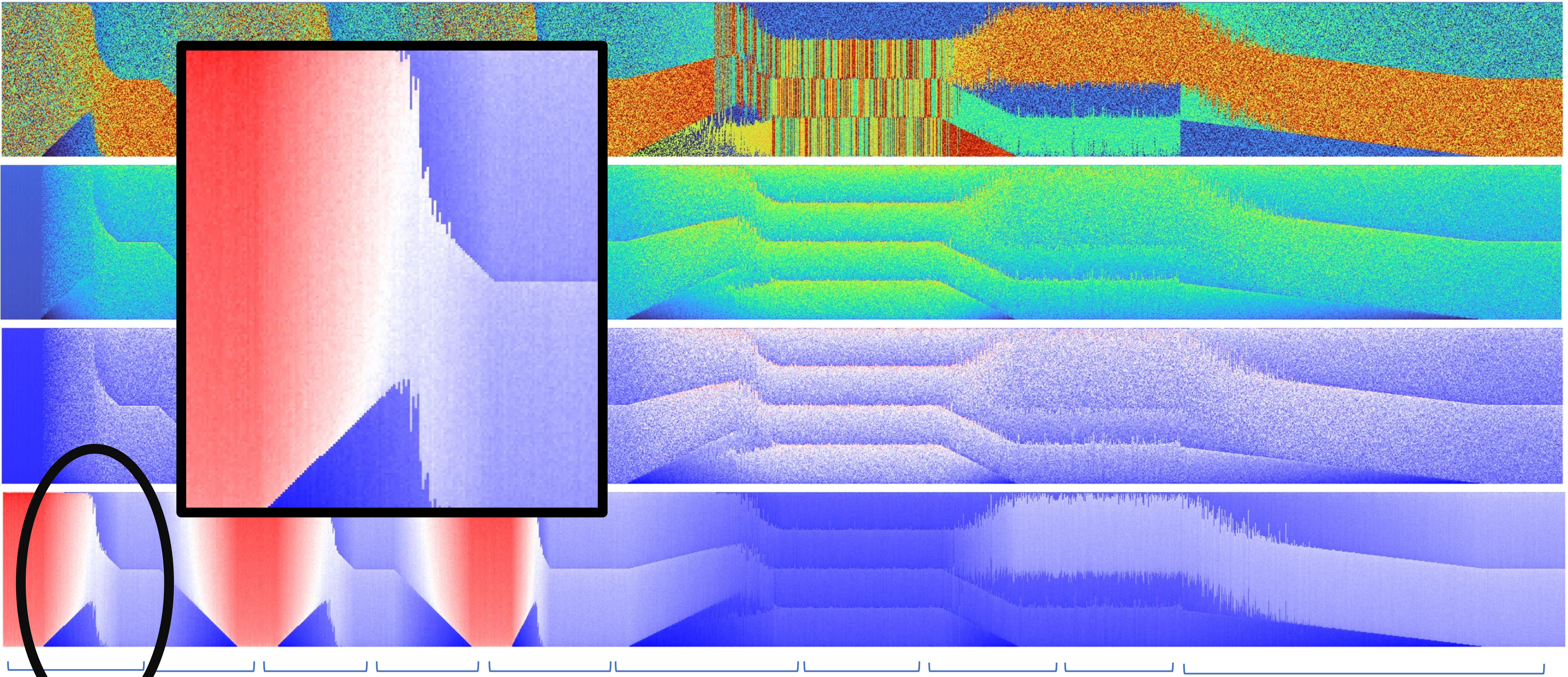
2000 time steps, 200 nodes



NetworkRug

Discussion + Results

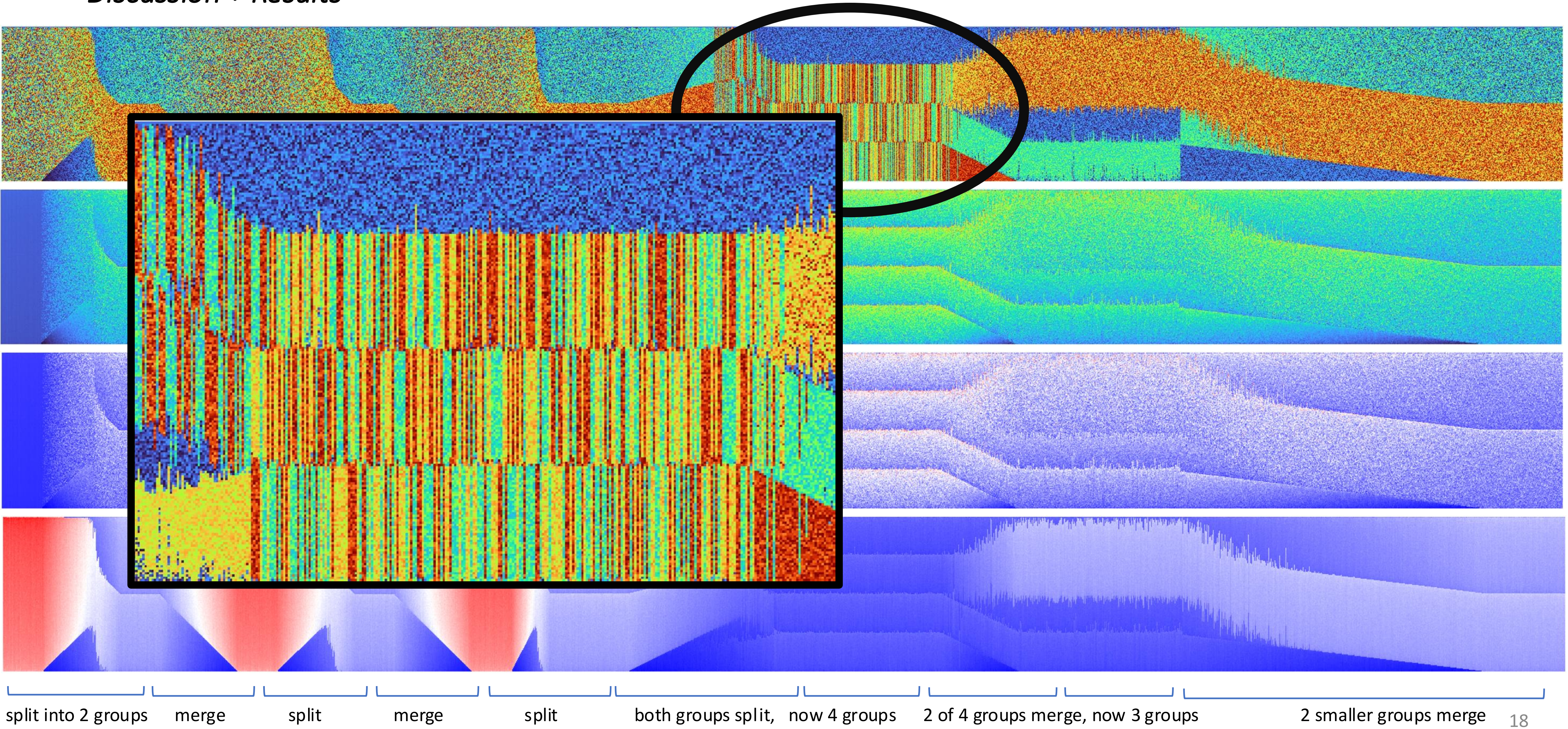
2000 time steps, 200 nodes



NetworkRug

Discussion + Results

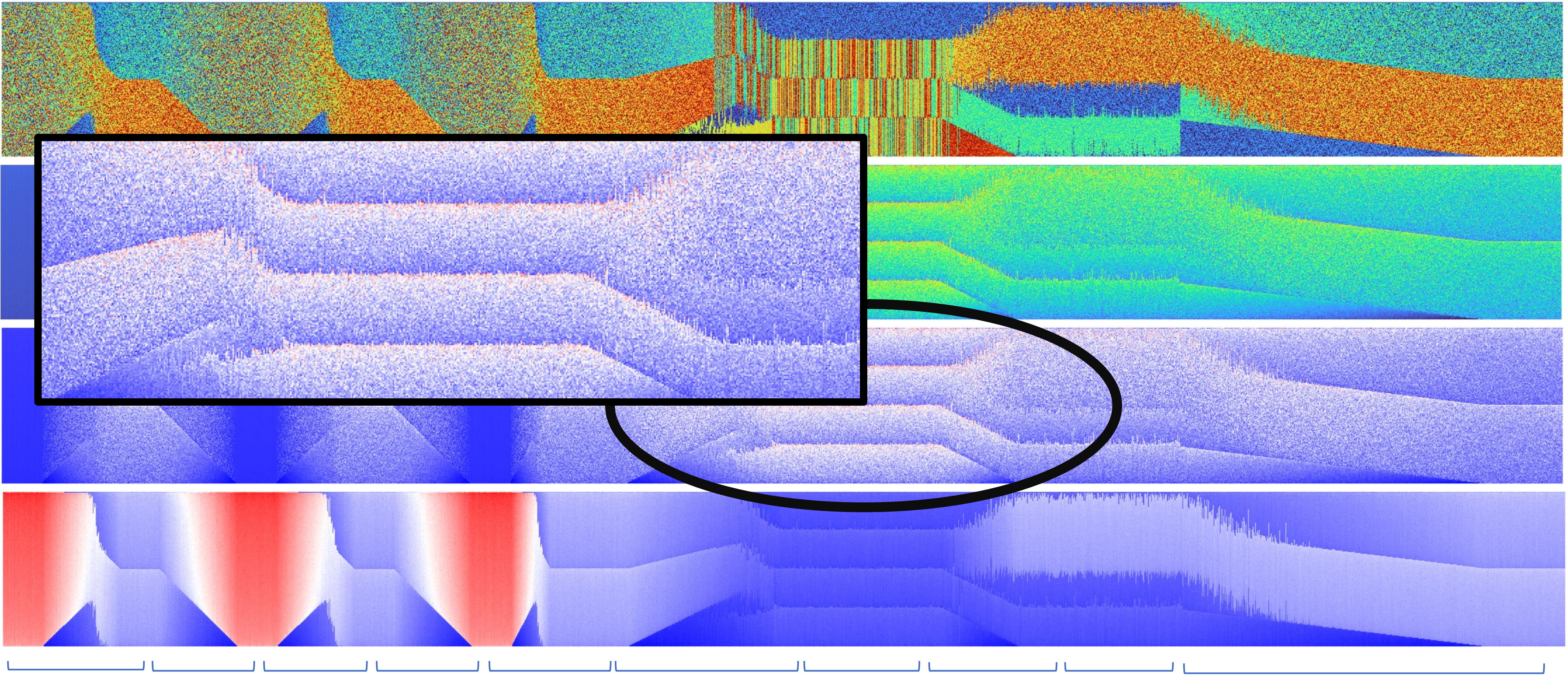
2000 time steps, 200 nodes



NetworkRug

Discussion + Results

2000 time steps, 200 nodes



split into 2 groups | merge | split | merge | split | both groups split, now 4 groups | 2 of 4 groups merge, now 3 groups | 2 smaller groups merge

Evaluation Results: Strengths

Discussion & Results

- Reveals group dynamics (splits, merges, growth, etc.)

- Priority-BFS outperforms other orderings

- Scalable: supports long timelines in compact format

- Semantic color encoding highlights structural + temporal change

Evaluation Results: Limitations

Discussion & Results

Visual & Computational Constraints

- Artifacts from ordering possible
- Node-level tracking limited
- High cost: ordering + centrality per timestep
- Color fails in disconnected graphs
- 1D layout hides topological detail

Structural & Applicability Limits

- Static node set
- Only non-overlapping communities
- Less clarity for complex simultaneous events
- Handling of outliers/disconnected components

Future Directions

Limitations & Future Work

- Improve Ordering + Temporal Stability
  - Decay Effect
- Broaden Evaluation Scope + Real World Applicability
- Extend Visualization

Conclusion

Conclusion

- Priority-BFS + NetworkRugs effectively reveal group structure changes

- Ordering strategy outperforms DFS, BFS and metrics

- Centrality coloring enhances visual clarity

- Limitations exist, but offer directions for future improvements

References

[1] Juri Buchmüller, Dominik Jackle, Eren Cakmak, Ulrik Brandes, and Daniel A. Keim. MotionRugs: Visualizing Collective Trends in Space and Time. IEEE Transactions on Visualization and Computer Graphics, 25(1):76–86, January 2019.

[2] Weiwei Cui, Xiting Wang, Shixia Liu, Nathalie H. Riche, Tara M. Madhyastha, Kwan Liu Ma, and Baining Guo. Let It Flow: A Static Method for Exploring Dynamic Graphs. In 2014 IEEE Pacific Visualization Symposium, pages 121–128, Yokohama, March 2014.IEEE.

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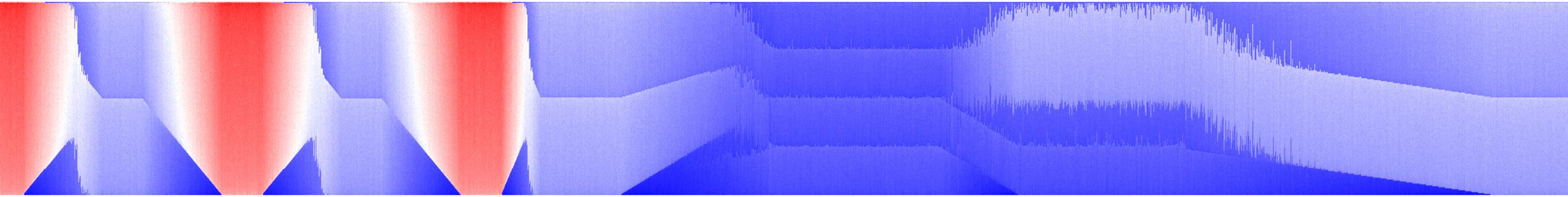

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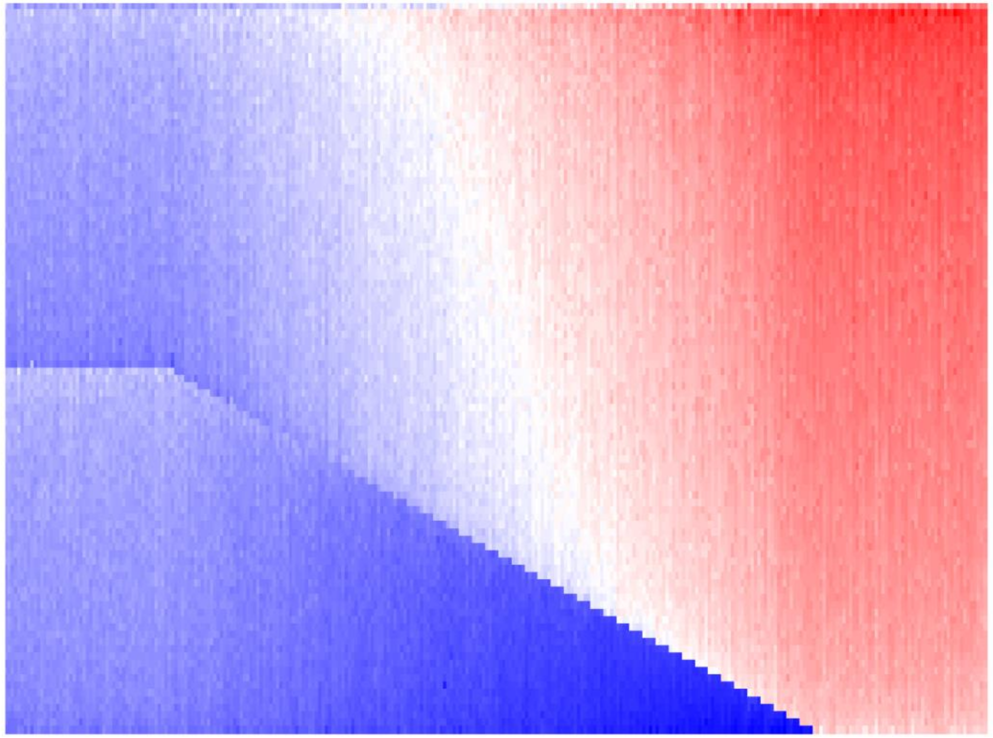
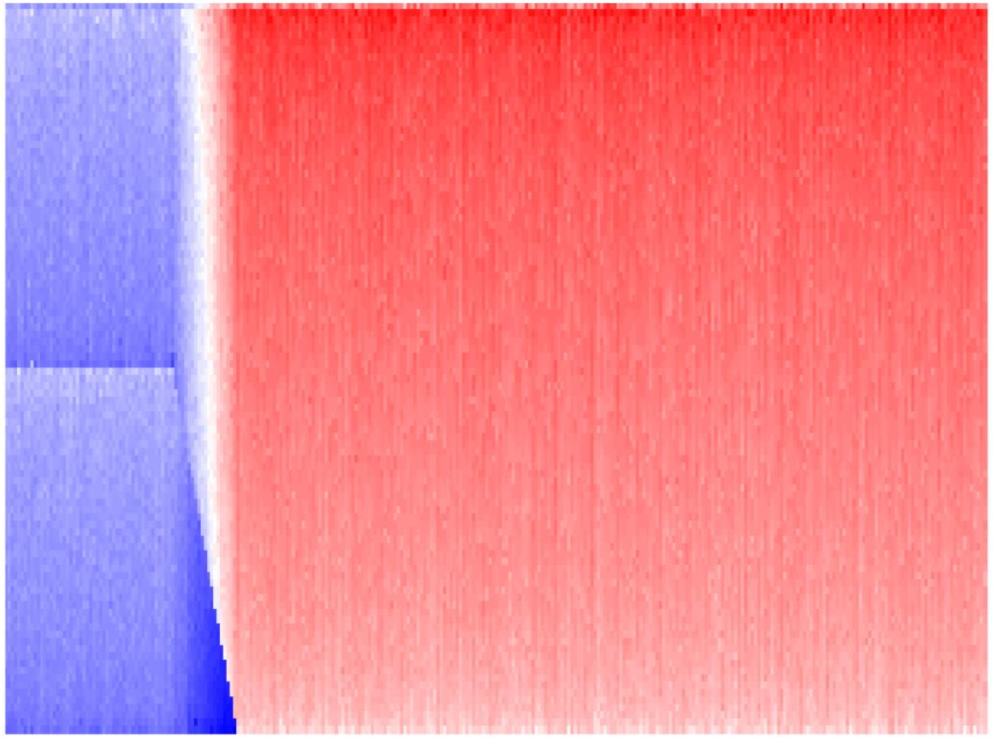
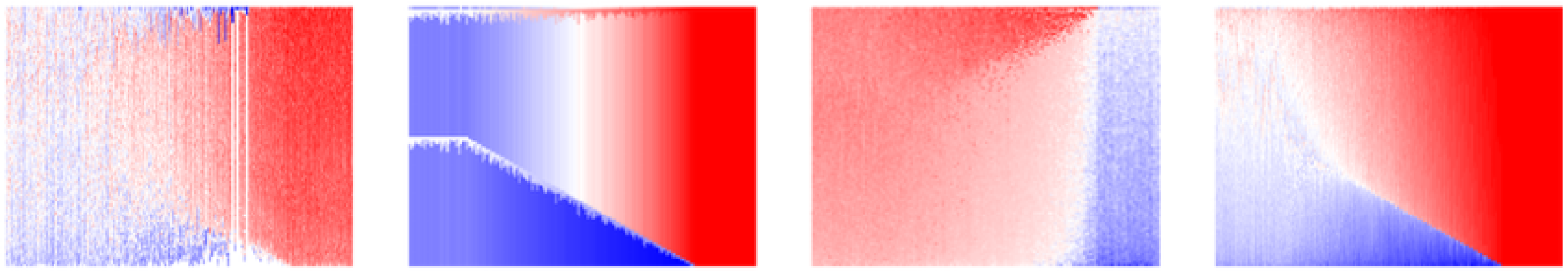
Rate of Change





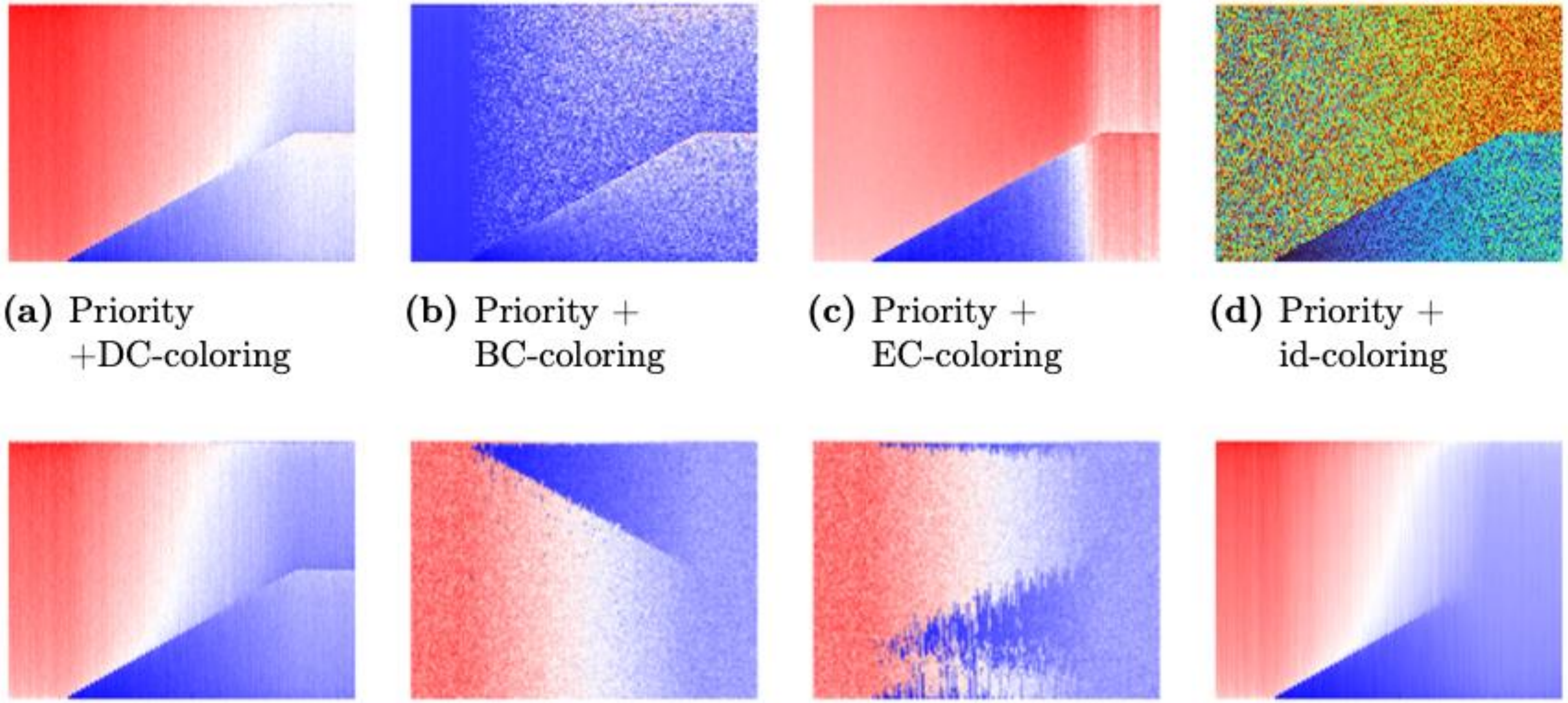
Network Structure



(a) weak, isolated (b) strong, isolated (c) weak, highly connected (d) strong, highly connected

Figure 14 The figure shows four extreme cases of network structure and their visual outcomes in a NetworkRug for a merge event involving two groups. All examples use CC-coloring. Subfigures (a) and (b) depict weak vs. strong intra-community connectivity under isolated conditions (i.e. minimal inter-group edges). Subfigures (c) and (d) show the same intra-group settings but with high inter-community connectivity, which blurs group boundaries. “Weak” refers to sparse internal connections within groups, while “strong” indicates dense intra-group linking. The comparison highlights how structural parameters such as intra- and inter-community density influence the clarity and coherence of visual patterns in the resulting rug.

Different Ordering Strategies



(a) Priority +DC-coloring

(b) Priority + BC-coloring

(c) Priority + EC-coloring

(d) Priority + id-coloring

(e) Priority + CC-coloring

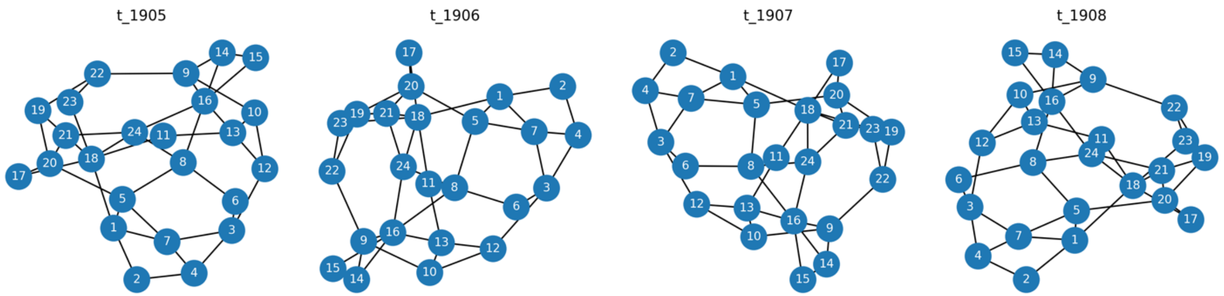
(f) DFS + CC-coloring

(g) BFS + CC-coloring

(h) Metric (degree) + CC-coloring

Different Dynamic Network Visualization Techniques

- Node-Link Diagrams



- Adjacency Matrices