Time-Aligned Edge Plots for Dynamic Graph Visualization

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What is a static graph?

\[ G := (V, E), \]

where \( V \) is set of vertices and \( E \) is set of edges \( E \subseteq V \times V \)
Graph Visualization

Node-link diagram (NL)

Adjacency Matrix (AM)
\[ \Gamma := (G_0, G_1, \ldots, G_{n-1}), \]

where \( G_i := (V_i, E_i) \) are static graphs and indices refer to a sequence of time points \( \tau := (t_0, t_1, \ldots, t_{n-1}) \)
Dynamic Graph Visualization

- Animation (time-to-time mapping)
  - Intuitive choice
  - But less effective form for analysis


Dynamic Graph Visualization

- Timeline (time-to-space mapping)
  - Small multiples
  - Not scalable in time

Small Multiples of Node-link diagram (SMNL)
Dynamic Graph Visualization

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Small Multiples of Adjacency Matrix (SMAM)
Time-Aligned Edge Plots (TEPs)

- A representation of dynamic graphs that is scalable in the time and edge dimensions
Time-Aligned Edge Plots (TEPs)

- We model the dynamic graph as a single super graph \[ G := (V, E) \]
- While edges are dynamically changing over time:
  \[ f_e(t): \mathbb{R} \rightarrow \mathbb{R}, t \in [t_{\min} \ldots t_{\max}] \]
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Time-Aligned Edge Plots (TEPs)
Problem 1

- It is hard to follow partially drawn edges

- Work-around
  - Reference Lines + User-adjustable
Problem 2

- Placing vertices in 1D vertical line results in a limited space for drawing edges and therefore increase visual clutter.

- Work-around
  - Slope Encoding
  - Vertex Ordering
Slope Encoding

Edges are drawn as opaque lines

Edges are blended by applying alpha compositing

Edges are blended, and slope is encoded by color
Vertex Ordering

- We combine Hierarchical Clustering (HC) with Simulated Annealing (SA)
- The similarity between two graph vertices \( v_i \) and \( v_j \) is obtained by calculating the Jaccard coefficient:

\[
J(\bar{V}_i, \bar{V}_j) = \frac{|\bar{V}_i \cap \bar{V}_j|}{|\bar{V}_i \cup \bar{V}_j|} \in [0, 1],
\]

where \( \bar{V}_i \) and \( \bar{V}_j \) are the sets of direct neighbors for vertices \( v_i \) and \( v_j \), respectively.
Vertex Ordering

Not ordered

Ordered
Problem 3

- Outliers may not be visible

- Work-around
  - Zoom Lens

Time-nonlinear Zooming Lens
Zoom Lens
Visual Patterns

**Structural Patterns**

- Fan
- Cluster
- Cross
- Cross-cluster

**Temporal Patterns**

- Stability
- Gap
- Periodicity
- Trend
- Phase shift
- Anomaly
Evaluation
Competitors

Massive Sequence Views (MSVs)


Interleaved Edge Splatting (IES)

Comparison

- **Theoretical and Empirical**
- Real-world and Synthetic data
- Three analysis tasks
- Qualitative Results Inspection (QRI)
Comparison

- Theoretical and Empirical
- **Real-world**\(^1\) and Synthetic data
- Three analysis tasks
- Qualitative Results Inspection (QRI)

\(^1\)Software call graph dataset (JHotDraw) http://www.jhotdraw.org/
Comparison

- Theoretical and Empirical
- Real-world\(^1\) and **Synthetic**\(^2\) data
- Three analysis tasks
- Qualitative Results Inspection (QRI)

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Comparison

- Theoretical and Empirical
- Real-world\(^1\) and Synthetic\(^2\) data
- **Three analysis tasks\(^3\)**
  - T1: Identifying node addition/removal events
  - T2: Identifying link addition/removal events
  - T3: Identifying temporal patterns (i.e., periodicity, stability, trend, outliers ...etc.)
- Qualitative Results Inspection (QRI)

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\(^2\)C. Cooper, A. Frieze, and J. Vera, "Random deletion in a scale-free random graph process," Internet Mathematics, vol. 1, no. 4, pp. 463–483, 2004
Comparison

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Findings
Findings (1)

- TEPs, MSVs, as well as, IES are scalable in the time dimension
Findings (2)

- TEPs, MSVs, as well as, IES are NOT suitable for node-related events

Small Multiples of NL  Massive Sequence Views  Interleaved Edge Splatting  Time-Aligned Edge Plots
Findings (3)

- TEPs is more scalable in the edge dimension

Small Multiples of NL  Massive Sequence Views  Interleaved Edge Splatting  Time-Aligned Edge Plots
Pixel Overdraw Metric

TEPs: 0.1247

MSVs: 3.3383

IES: 8.0545
Findings (4)

- TEPs reveal more link events and temporal patterns
Findings (5)

- It is very hard to recognize edges in MSVs due to the lack of slope encoding.

Small Multiples of NL  Massive Sequence Views  Interleaved Edge Splatting  Time-Aligned Edge Plots
Findings (6)

- Without reference lines, it is hard to identify the source and target nodes in TEPs
In TEPs, the shape of the structural patterns changes over time.

Findings (7)

Fan-out pattern depicted over time
TEPs: a novel visualization approach that is scalable in the edge and time dimensions

To amplify the recognition of edges:
- Drawing Ref. Lines
- Zoom Lens
- Vertex Ordering
- Slope Encoding

Evaluation is done through a comparative QRI versus MSVs and IES
- Theoretically and empirically
- Synthetic and real-world datasets
- Three analysis tasks

TEPs reduce the amount of visual clutter significantly allowing us to see more edge events and temporal patterns

However, it might be difficult to determine the source and target nodes of certain events

TEPs can serve as an entry point for analyzing networks

Conclusion
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