Unfolding Edges for Exploring Multivariate Edge Attributes in Graphs

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Abstract

With this research we present an approach to network visualization that expands the capabilities for visual encoding and interactive exploration through edges in node-link diagrams. Compared to the various possibilities for visual and interactive properties of nodes, there are few techniques for interactive visualization of multivariate edge attributes in node-link diagrams. Visualization of edge attributes is oftentimes limited by occlusion and space issues of methods that globally encode attributes in a node-link diagram for all edges, not sufficiently exploiting the potential of interaction. Building up on existing techniques for edge encoding and interaction, we propose 'Unfolding Edges' as an exemplary use of an on-demand detail enhancing approach for exploration of multivariate edge attributes.

CCS Concepts

• ***Human-centered computing*** → ***Visualization techniques; Graph drawings; Interaction design;***

1. Introduction

Multivariate network visualization is about visual depictions of graphs whose nodes and edges hold additional, potentially heterogeneous data attributes [NMSL19, KPW14]. Even though edge attributes such as weight or direction are regularly encoded in node-link diagrams (NLD), more complex variations of edge attributes are difficult to represent in graph visualizations. The main problem in encoding multivariate edge attributes in NLD lies in the practice of adding on-edge encoding globally to all edges, typically leading to over-plotting of relevant information. Although NLD are applied widely for various exploration and analysis tasks [OJK19, NWHL20, NMSL19], there are surprisingly few techniques that focus on addressing space limitations of edge attribute representation through interaction.

In a recent state-of-the-art report on the visualization of multivariate networks, Nobre et al. conclude that while a variety of techniques exists to visualize node attributes, more research is needed on visualizing edge attributes as well as on interaction with them [NMSL19]. Echoing this call and based on the need for new techniques to facilitate exploration of multivariate edge attributes, our work focuses on interactive on-demand techniques for visualizing edge attributes in NLD. We argue that the possibilities of combining visual encoding of and interaction with edges and their attributes with the goal to enhance visualization possibilities in the sparse space of NLD are not sufficiently explored yet. This work summarizes prior research and proposes 'Unfolding Edges' as a technique that expands the encoding and exploration capabilities of edges in NLD.

2. Background and Related Work

In NLD it is common to visualize edge attributes via direct on-edge encoding using different visual variables [KPW14, NMSL19]. Several examples are illustrated in Fig. 1, including line width for edge weight [Wat06], color for edge type [BNML19], fuzziness for uncertainty [GHL15], animated particles for direction of movements [RAB*18], arrows or gradients for edge direction [HIvF11], sub-edges or line curvature for displaying multiple edges in parallel [KAW*14, RDLC12], compressing edges to oscillating waves for a representation of edge length [NJBJ09], and finally small embedded visualizations for multivariate edge attributes [SSSE16]. Despite this variety of possibilities for visualization of edge attributes, in practice their individual and combined use is often challenging. The space for edges—usually represented through a thin line—is restricted and the encoding and interaction with them suffers from occlusion through other edges [NMSL19, RDLC12]. Existing techniques for encoding attribute values on edges in NLD oftentimes do so globally, that is, the encoding is added for all edges at the same time, which usually leads to visualizations that do not scale well or to cluttered displays and occlusion [KPW14, NMSL19].

Researchers already provide a variety of possibilities to address similar challenges through on-demand integrated detail enhancements in the context of node attributes [NMSL19] or in other graph visualization types (e.g., adjacency matrices [HBS*21]). Nevertheless, approaches using interaction to enhance edge attribute details in NLD are so far limited. Interaction with edges is useful, for example, for selection or to resolve complexity by filter-

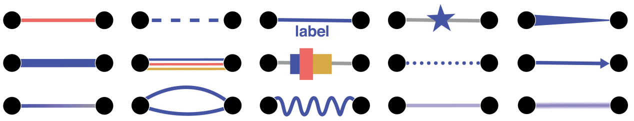

Figure 1: *Exemplary variants of on-edge encoding. 1st row: color, texture, label, added glyph, tapering; 2nd row: line thickness, parallel lines, small embedded visualizations, animation, arrows; 3rd row: gradient, curvature, oscillation, transparency, blurring.*

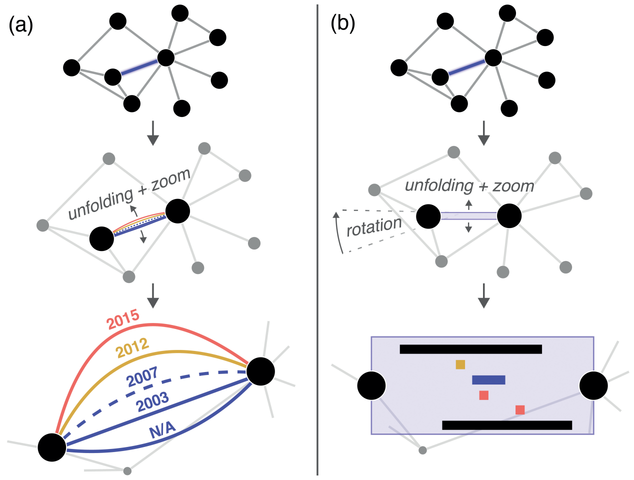

Figure 2: *Two exemplary variations of 'Unfolding Edges' where selection of an edge (top) triggers a transition (middle) towards a new on-demand visualization state with increased edge details (bottom): (a) a selected edge is separated into multiple sub-edges, allowing additional data encoding possibilities for each sub-edge; (b) a graph is rotated to bring a selected edge into the horizontal position and the edge unfolds into additional space for a timeline.*

ing [NMSL19], for interactive dissection and attribute-based cross-filtered views [Wea10], for rolling up edges [Wat06], or for edge-driven navigation [TAS09]. Edge interaction has also been applied to enhance readability, e.g., by using edge plucking [WC07], edge bundling [Hol06], interactive link curvature [RDLC12], edge expansion [FHH*20], edge lenses [WCG03, TAvS06], or multi-touch gestures [SNDC10]. In contrast to these techniques that are intended to increase readability or to minimize occlusions, our aim is to interactively add more detail to selected edges.

3. Unfolding Edges

Our approach is inspired by focus+context [CKB09], semantic zooming [PF93], and fluid interaction [EMJ*11]. To enhance the possibilities for visualization of multivariate edge attributes, we want to extend the interactive capabilities and visual encodings of edges and shift the focus to *unfolding* of edge details on demand. With unfolding we refer to situated and transitioned detail enhancements that are induced through interaction [BBD20]. With this, the overall complexity in a visualization can be kept low and edge attribute encoding strategies can be used individually and in combined form without additionally cluttering a visualization. In contrast to exposing just a specific data dimension of an edge by using only one edge encoding possibility, we envision combinations of multiple forms of encoding for multiple attributes. By using interactivity and transitions to unfold these additional attribute details on demand and integrating these details into the same view, details could be enhanced without losing the global context, facilitating open-ended exploration of other nodes and edges.

Fig. 2 displays two exemplary manifestations of on-demand edge unfolding. In both examples, a selected edge transitions into a more detailed representation. By utilizing semantic zooming and muting down unrelated parts of the graph, the visualization offers more space for adding details while keeping the context intact. Fig. 2 (a) showcases a form of edge fanning, similar to approaches by Riche et al. [RDLC12] and Fujita et al. [FHH*20]. Here, varying curvatures of unfolded sub-edges are used to display multiple source types (color), involvement of uncertainty (dash pattern), and ordering and labels to display multiple temporal dimensions of a link. Fig. 2 (b) uses zoom and rotation to bring a selected edge to a horizontal position. The edge is then unfolded to create a rectangular space into which a small color-coded timeline visualization can be embedded. This type of unfolding enables the on-demand exploration of temporal aspects of the connectivity in a graph.

We see potential applications of the edge unfolding particularly for historical network analysis, where observation of individual links between nodes and their attributes or sources are central factors for interpretation and trust in a visualization. In historical network analysis, links between actors are usually based on historical documents such as messages or letters [RDGSS17, NMM*14]. Here, individual edges between nodes are not only based on one source or relation type, but may be constructed from multiple sources/types with varying additional attributes, such as certainty, duration, direction, dating, and more. The examples of Fig. 2 only feature two potential use-cases, but depending on the data and domain, many other techniques and use-cases are imaginable.

4. Conclusion and Future Work

We envision 'Unfolding Edges' as a starting point for a family of novel and more scalable multivariate edge attribute visualization techniques in the future. First interviews and discussions with domain experts already hint to promising results, although formal evaluation is still pending. The proposed techniques trade the possibility of more elaborate local detail enhancements against global edge encoding possibilities, currently limiting the potential to tasks focused on individual edges. More development is needed to consider tasks involving several edges (e.g., comparison). Further questions remain: *How to facilitate interaction with edges? How to foreshadow enhanceable detail? How could on-demand enhancement of edge details be used for global tasks?* By researching these and further open questions, we aim to come up with a comprehensive design space for interactive edge visualization.

5. Acknowledgements

This work is funded by the German Research Foundation (grant no. 414792379 (SoNAR IDH) and grant no. 214484876 (GEMS 2.0)).

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