Hybrid Multilayer Network Visualization of Bibliographic Data

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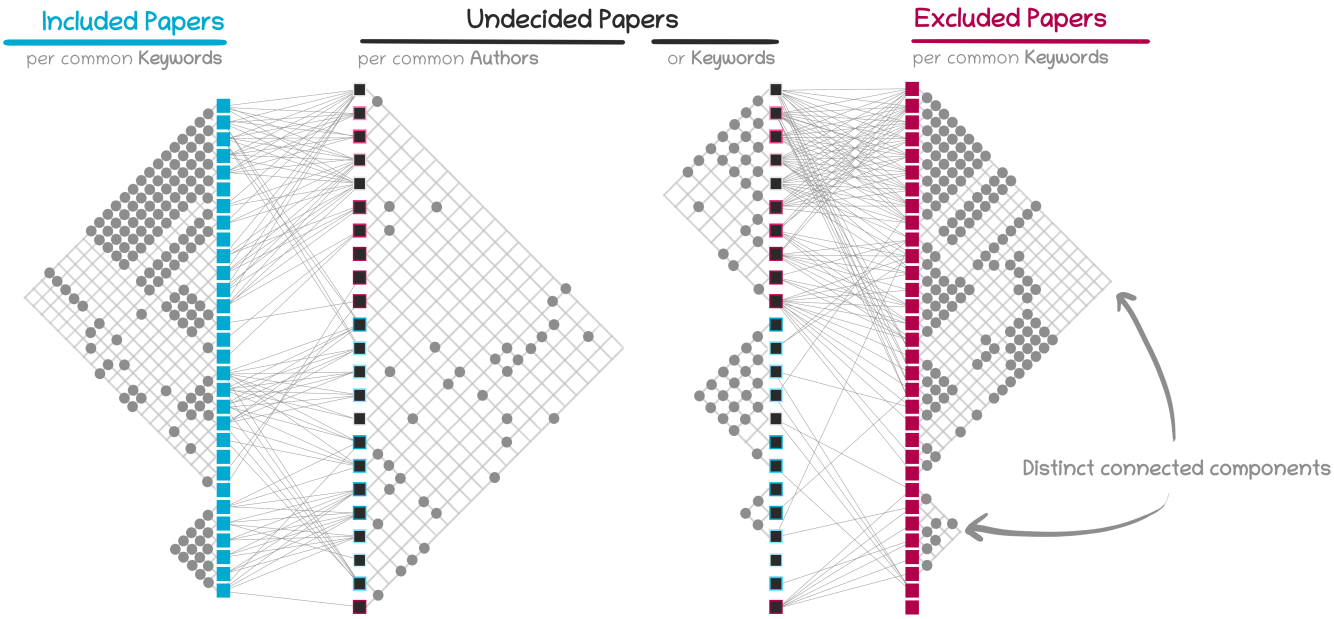

Figure 1: *A sketch illustrating a hybrid visualization of adjacency matrix and parallel-axis node-link layout for paper screening.*

Abstract

To reify the concept of layers, multilayer network visualizations often lay out nodes on distinct hyperplanes, one per layer. In this work, we consider the case of a 2D representation where layer nodes are laid out on parallel rectilinear axes. The adoption of classic edge drawing strategies here would lead to much visual clutter due to overlapping inter-layer and intra-layer edges. Moreover, distinguishing between these two types of edges would be fairly difficult. In this preliminary work, we explore the potential of using a hybrid visualization blending the adjacency matrix and node-link metaphors to distinguish undirected intra- and inter-layer edges, respectively. We apply this approach to the analysis of bibliographic data, and discuss current limitations.

CCS Concepts

• ***Human-centered computing*** → ***Graph drawings;*** *Visual analytics;*

1. Introduction

Multilayer networks model complex relationships between entities by dividing them into layers, based on the type of entity or relation, on timeframe, or on any combination of properties [KAB*14]. These layers may overlap and are often interconnected. The diversity of sources and targets makes it hard to visually locate and distinguish intra- and inter-layer edges in classic node-link layouts. To make these concepts easier to grasp and handle, we set out to explore alternative visual designs of such interconnected layers.

Matrix-based visualizations are known to be more readable for many network analysis tasks [GFC05; NMSL19; OJK19]. Examples in multilayer settings include juxtaposed matrices as

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small multiples, one per layer [LS15], or one matrix filled with layer-specific marks varying in color, position and/or orientation [VABK20]. Although these approaches show the diversity of layers, they do not display inter-layer edges. Other embeddings may lay out nodes in 1D, 2D or more [MGM*19; MRA*21], drawing edges between and within layers which can in turn be juxtaposed [FPK*23; DPA15] or superposed [ZB16], raising different challenges for the visualization of all types of edges. Here, we propose a hybrid visualization providing distinct visual identities for both intra- and inter-layer edges.

2. Visual design

Hybrid visualizations were proposed to support the analysis of locally dense networks, e.g., embedding matrices [HFM07] or chord diagrams [ADM*22] in node-link representations. Here, we apply the same logic to layers instead of clusters of nodes, effectively adopting distinct metaphors for edges within and between layers, as illustrated in Figure 1. Like in the *Parallel Node Link Bands* [GKL*13], we lay out nodes on parallel axes, one per layer, and draw inter-layer edges as straight lines. To depict intra-layer edges, we use the triangular half of an adjacency matrix with nodes placed on the diagonal. This makes it easy to align the nodes in the node-link and matrix parts. Each edge is depicted by a gray circle at the intersection of the rows and columns corresponding to its extremities (see Figure 1).

This encoding not only gives a distinct visual identity to intra-layer edges, but it also avoids the redundant encoding of edges in undirected networks, typical of adjacency matrices [HFM07]. This approach is reminiscent of Hi-C contact maps [YN17], often represented as triangular heatmaps showing the intensity of interactions amongst all positions within a portion of genome. Node order allowing, distinct partial grids (triangles) can be drawn for each connected component rather than for the whole layer, saving space. See, for example, the 'Undecided Papers' layer in Figure 1, where author-based links appear in a full triangular grid, whereas keyword-based links are inscribed in smaller, more local grids.

As all nodes of a layer are placed at the base of the grids, inter-layer edges can be drawn as lines between any pair of adjacent layers without overlap when their grids are facing outward. Additionally, nodes can be ordered to reveal intra-layer patterns, or to reduce the crossings between inter-layer edges [Lii10; Nag05].

3. Application to decision-making in paper screening

To test the practicality and efficiency of our representation, we applied it to support making decisions about the inclusion or exclusion of papers during a literature review project. The process starts with a search query into several scientific databases, which returns a list of (thousands of) papers and related metadata. This corpus can be augmented further through a step of forward or backward snowballing to capture citation relationships between papers. The paper screening step consists in narrowing down the list of papers to only keep relevant work to support writing the final literature review.

Various relationships between authors, papers, conferences, and institutions can be derived from such a corpus and turned into various kinds of bibliometric networks [vEW14] or network layers. Our goal is to build a multilayer network and use it to propagate information between papers labeled for inclusion/exclusion by the user. Our layers are defined as subnetworks based on papers sharing the same decision label, connected by a shared property, whether raw (authors, keywords, conference, citations, or references from metadata) or derived, like paper similarity scores based on titles or abstracts. These layers would update dynamically as users annotate more papers. The resulting subnetworks are undirected, and can split into multiple connected components. Many papers might even be isolated, depending on which relationships are considered. Also, creating edges by projection may give rise to cliques, as is the case for co-authorship links between papers. In some scenarios, the number of edges obtained by projection could soar dramatically, for example when based on shared conference or more interestingly shared terms. Node seriation makes clusters of undecided papers emerge visually within the adjacency matrix component of our hybrid representation, with strong links to papers labeled for inclusion/exclusion. Investigating these patterns promises to help users make decisions about groups of papers at once.

Our current Web-based prototype leverages the React framework and the graphology.js library to create network structures. We built a network of 233 papers (all connected through snowballing), as part of a survey on scented widgets [CMM*23]. Similar to Figure 1, undecided paper grids are displayed in the middle while the included and excluded papers are placed at opposite sides. Inter-layer edges could model an attraction score of undecided papers towards one or the other side, i.e., inclusion/exclusion decision. The adjacency grids representing the intra-layer edges provide contextual information, explaining inferred paper scores, and a basis for the identification of groups of papers suited for batch decisions.

4. Opportunities

This preliminary work can be extended in many ways. This includes user interactions to support the exploration and manipulation of the displayed data, on laptops and large wall displays. Also, we have focused so far on the visualization of three layers at a time only. We would like to scale up to more layers, for example via the superposition of layers having shared entities, hence supporting comparison as was done for matrices [VABK20; ZWL*22]. Another option is the juxtaposition of grids [LS15], each with connections to other sets of layers in constellations similar to many-to-many parallel coordinate plots [CvW11].

One could also address the problem of representing inter-layer edges from one to multiple distant layers while minimizing visual occlusion. Exploring circular grid layouts would be another option for showing these edges in a many-to many layer setting. We also wish to investigate the scalability of grids for layers with many nodes and interconnections. Further, we tailored our representation for undirected graphs. Exploring representations of directed edges in such a visual encoding could be an interesting extension.

Finally, we intend to study the use of edge bundling to reduce inter-layer edge crossings. Our idea is to design ad-hoc bundling strategies based on confluent drawings [EGM07] and/or simplification of *fan crossings*, i.e., crossings caused by a group of edges incident to a node that intersect the same edge [BDD*15].

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