

# Show Me Similar Nodes: The Similarity Lens for Multivariate Graphs

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## Abstract

*Node-link diagrams with topology-driven layouts are effective tools for visually exploring the structure of graphs. When exploring multivariate graphs, a frequent analytical question is to ask which graph nodes are similar in terms of their multivariate attribute values. Answering this question would usually involve switching to an attribute-driven layout or a different visual representation altogether. However, such context switches may ensue additional cognitive costs and hinder the fluent exploration of the graph. In this paper, we present an interactive lens technique, called the similarity lens. It avoids global view changes by dynamically injecting a local attribute-driven layout into an otherwise topology-driven layout. Given a focus node of interest in the center of the lens, dissimilar nodes are pushed out of the lens and similar nodes are pulled inward, with the most similar nodes closest to the focus node. This dynamic layout adaptation facilitates comparison tasks on a local level without disturbing the user's overall mental map of the graph topology too much. We demonstrate the utility of our approach by exploring a real-world multivariate graph of soccer players.*

## CCS Concepts

• **Human-centered computing** → **Visualization techniques; Interaction techniques;**

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## 1. Introduction

Supporting the visual analysis of multivariate graphs is challenging. The reason is that a comprehensive understanding of multivariate graphs requires visual representations that communicate the topological structure of a graph and its associated multivariate attributes [KPW14]. The base line for our work is a topology-representing node-link diagram where one or two selected node attributes are visualized via on-node encoding [NMSL19]. With this standard approach, finding similarities among the multivariate nodes is difficult, because relevant nodes could be spatially far apart in the layout, which complicates their comparison.

Alternatively, one could use an attribute-driven layout where node coordinates are set based on attribute values. This brings similar nodes spatially close to each other and makes comparisons easier. However, switching to an attribute-driven layout usually means that the representation of the graph topology is compromised or even neglected altogether. This would make it hard or even impossible to develop or maintain a mental map of the graph structure.

Our goal is to support the flexible exploration of multivariate node similarities while keeping the overall graph topology in a node-link diagram intact. To this end, some form of hybrid layout is required where topological aspects and multivariate attribute values can co-exist, not globally but for a dynamically changing focus node of interest. Inspired by previous work on dynamic layout

adaptations, we propose the *similarity lens* as a lightweight interactive tool that can induce transient layout changes into a node-link diagram to make the exploration of node similarities easier. Within the lens, nodes are laid out according to their multivariate similarity with respect to a selected focus node, which makes understanding how similar the nodes are straightforward. Thanks to the focus+context nature of our lens, the overall topology-driven layout is changed only locally so that the cognitive load is reduced and the overall mental map easier to preserve.

After reviewing related work in Section 2, we describe the similarity lens in detail in Section 3. Section 4 demonstrates our technique for a multivariate network of soccer players. Section 5 closes with a summary and ideas for future work. A prototype implementation is available at: <https://t1p.de/sim-lens>.

## 2. Related Work

Our work is related to previous research in multivariate graph visualization, visual comparison, and dynamic adaptation of visualizations through user interactions.

**Visualizing Multivariate Graphs** Multivariate graph visualization is comprehensively discussed in the literature [KPW14; NMSL19]. Typically, basic techniques such as node-link diagrams

or matrix representations are extended to display the multivariate attributes of a graph, for example by incorporating additional views [NSL19], embedding additional encodings [BST19], or laying out the graph based on its attributes [WT08]. In this work, we focus on node-link diagrams.

Two types of layouts for placing nodes in node-link diagrams exist: topology-driven and attribute-driven layouts. Topology-driven layout algorithms such as the force-directed layout [FR91] aim to make the graph topology visible. Attributes can then be represented via additional encodings on the graph nodes [vdEvW14; NMSL19]. On the other hand, attribute-driven algorithms place nodes according to their attribute values, for example, as groups in shared regions [SA06; RMS\*11], in diagram-like coordinate systems [BCD\*10; EGST16], or via multi-dimensional scaling [DCW11]. In this work, we aim to combine the advantages of topology-driven and attribute-driven layouts specifically for the task of finding similar nodes in a graph topology.

**Visual Comparison** Finding similarities (and differences) is a frequent task in visual analysis settings. As a compound task it entails identifying data elements and relating them through visual comparison [SNHS13]. Three general approaches to visual comparison can be categorized: juxtaposition, superposition, and direct encoding [GAW\*11]. They are also applied to specifically support visual comparison in graphs, for example, by juxtaposed layouts [AWW09] or superposition of edge information [ABH\*13].

While assessing similarities can be easier with dedicated comparison views, they might not be optimal for other analysis tasks. Natural interaction techniques can help users to dynamically create comparison layouts on the fly to best suit the task at hand [TFJ12]. Here we pick up the idea of dynamically adapting a visualization on demand to facilitate similarity exploration.

**Dynamic Adaptation of Visualizations** The goal of dynamic visualization adaptations is to provide flexible access to different perspectives on the data while maintaining the general context [BBD20; TAA\*21; HBS\*21]. Instead of abrupt switches between views, smooth transitions take users from one perspective to another to keep users in the flow [EMJ\*11].

Focus+context approaches have long been used for dynamic adaptation of a region of interest [CKB08]. A prominent example of focus+context techniques is interactive lenses, which induce transient visual changes into an existing visualization [TGK\*17]. Common lens techniques dynamically distort space to magnify interesting data [SB94] or rearrange graphical elements to filter out uninteresting data [HTE11]. In node-link diagrams, lenses can dynamically adapt the layout to create local neighborhood overviews [TAS09] or support navigation via *bring & go* [MCH\*09]. Lenses can also be used to reveal additional details about node attributes [JDK10]. A lens-like technique that supports visual comparison is the *CompaRing* [Tom16]. It implements a *bring & compare* strategy that creates an on-demand juxtaposition of geographic regions to be assessed for similarity.

Inspired by these previous works, we propose a lens technique that dynamically adapts the layout in node-link diagrams to facilitate the exploration of similarities among graph nodes in terms of their multivariate attribute values.

### 3. Approach

Based on our own experience in exploring node-link diagrams and working with dynamically changing visual representations, we set the following design goals:

**G1 Support similarity exploration:** Given an existing node-link diagram, it should be possible to effortlessly explore nodes with respect to their multivariate similarity.

**G2 Preserve mental map:** The user's mental map of the global graph topology should be preserved by reducing global layout changes to a necessary minimum.

**G3 Maintain analysis flow:** To keep users in the analysis flow, smooth display transitions should be favored over disruptive view switches.

Our starting point is a force-directed node-link diagram that represents the graph topology. Node size and color can optionally be used to visualize selected node attributes. Zooming and panning facilitates the exploration of the graph.

To ease the study of attribute-based node similarity in this setting, our approach locally transforms the node-link diagram. Placing the similarity lens on a focus node of interest triggers an attribute-driven layout transformation that brings similar nodes with respect to the focus node into the lens (G1). This layout change is restricted locally to the similar nodes so that the topology-driven layout is mostly preserved (G2). A force-based animation smoothly pulls nodes into the lens or pushes them away as the user activates or deactivates the lens or changes the focus node (G3).

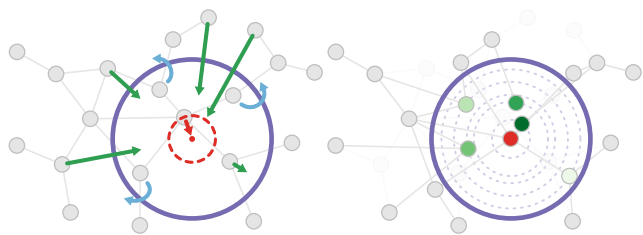
Next, we describe how exactly nodes are placed in the lens and how visual enhancements and interactivity support its use.

#### 3.1. Lens-based Dynamic Layout Adaptation

As illustrated in Figure 1 (left), the lens is defined by a focal point (red), an inner focus ring (dashed red), and an outer effect ring (solid violet). The inner focus ring is used to capture the focus node, whereas the outer effect ring determines how much space will be used for the injected attribute-driven layout.

**Select focus node** The focus node is selected by moving the lens across the graph layout. If there is a node inside the (reasonably small) focus ring, it becomes the focus node and is centered within the lens (red arrow in Figure 1, left). If there are multiple nodes within the focus ring, the nearest node to the focal point is chosen. If there are no nodes inside the focus ring, the lens has no effect. Alternatively, a node can be focused by clicking or tapping, which automatically positions the lens on top of it.

**Determine similar nodes** Once a focus node has been specified, the lens interior transforms to an attribute-driven layout that visualizes the similarity of the focus node to other *relevant* nodes. Different plausible criteria exist to determine which other nodes should be deemed relevant. One could consider the topological  $k$ -neighborhood of the focus node or the view neighborhood within a certain window around the lens. As we are primarily interested in node attributes, we use the "attribute neighborhood" of the focus node, which boils down to considering the similarity of nodes according to their multivariate attribute values.



**Figure 1:** Schematic illustration of the lens-based dynamic layout adaptation (left) and visual enhancements (right). Left: The focus node is centered (red arrow), nodes that meet the similarity threshold are placed according to their similarity with respect to the focus (green arrows), and nodes that do not meet the similarity threshold are moved out of the lens (blue arrows). Right: Color coding and radial guides further indicate the nodes' attribute-based similarity.

The similarity lens utilizes a pre-calculated matrix that stores the attribute-based similarity (e.g., Euclidean distance, cosine similarity, or Pearson correlation coefficient) of all pairs of nodes. Which nodes are ultimately considered relevant is determined based on a similarity threshold. This threshold can be set interactively or controlled automatically to limit the number of affected nodes.

**Adapt graph layout** As indicated by the green arrows in Figure 1 (left), nodes that satisfy the threshold, and are thus of interest to the user, are re-positioned inside the lens. Nodes that are most similar to the focus node are pulled close toward it. Nodes that just meet the similarity threshold are positioned on the lens boundary. Moreover, any nodes within the lens that fail to meet the similarity threshold are shifted just beyond the lens border as shown with blue arrows in Figure 1. Attracting relevant nodes to the lens and repelling irrelevant nodes from the lens can be considered a combination of previously described lens effects from the BringNeighbors lens [TAvS06] and the MoleView lens [HTE11]. A smooth, force-based animation injects the attribute-driven changes into the overall topology-driven layout. The comprehensibility of this adaptation certainly depends on a well-chosen similarity threshold that limits the number of affected nodes to a reasonable level.

As a result of this transformation, all nodes that are similar to the focus node are placed inside the lens. Their distances to the lens center represent their similarity. Their orientations with respect to the lens center indicate the nodes' original position in the graph layout. With all relevant nodes locally pooled, they can now be better compared to the focus node and to each other. As the transformation also affects the display of edges, one can even study how the similar nodes are connected in the graph topology. By moving the lens or by selecting another focus node (e.g., from among the re-located nodes), users may continue the data exploration.

While the layout adaptation can already make similarities easier to assess, visual enhancements can provide additional support.

### 3.2. Visual Enhancements

For assessing the similarity of two nodes, their corresponding distances to the lens center must be compared. This can still be difficult, if the two nodes are far apart in the lens. To address this

issue, additional visual cues can be activated. A first option is to color-code the similarity value on the nodes as show in Figure 1 (right). This facilitates comparison tasks, but sacrifices the original on-node encoding for the nodes inside the lens.

Secondly, concentric circles can be embedded in the lens, acting as radial guides similar to [MCH\*09]. The radial guides make it much easier to compare the nodes' distance to the center, as can be seen in Figure 1 (right). Users can choose from three different modes: (i) fixed equidistant circles, (ii) fixed circles per node inside the lens, and (iii) a dynamic circle that is linked to the cursor and optionally snaps to nodes. The different modes allow users to apply the radial guides in a task-specific manner. Exploratory analysis phases could be supported with a dynamic circle, whereas a few fixed circles can serve confirmatory or presentation purposes.

A final visual enhancement addresses in-lens edge clutter. To clear the lens interior of edge clutter, we integrate an additional lens effect, originally proposed as LocalEdge lens [TAvS06]. It suppresses edges inside the lens that do not connect to in-lens nodes. This effectively means that the lens shows only those edges that have at least one incident node inside the lens. By requiring that both nodes of an edge must be inside the lens for edges to be visible, the topology representation in the lens can be further reduced to focus entirely on the similar nodes.

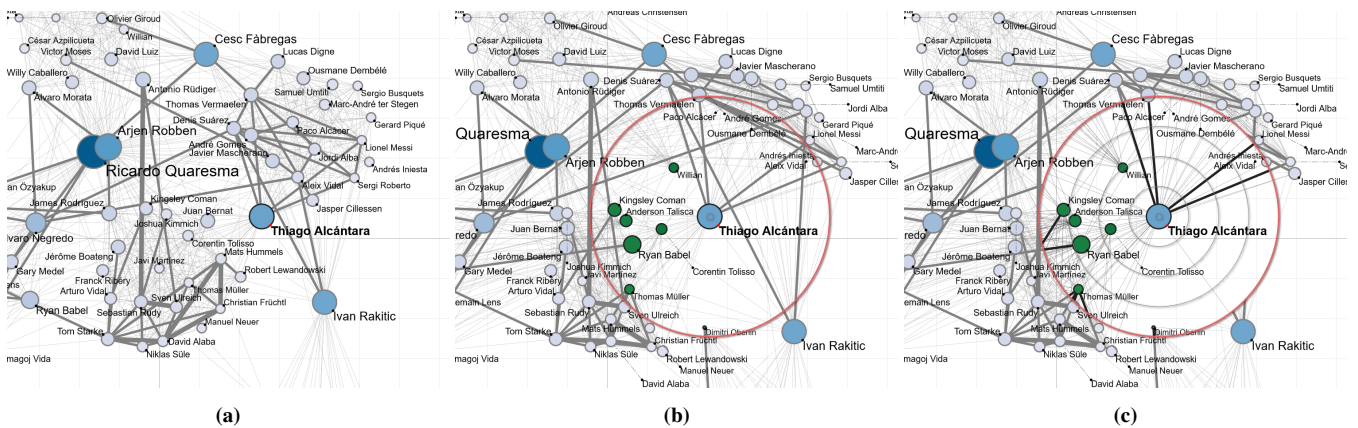
The described visual enhancements as well as the dynamic layout adaptation and the lens itself can be adjusted via user interaction as described next.

### 3.3. User Interaction

As already mentioned, a basic interaction is to select a focus node of interest by moving the lens via drag gestures or clicking on nodes. Further, the lens size can be adjusted directly via the mouse wheel. This makes it possible to balance the display space dedicated to the attribute-based view inside the lens and the preservation of the graph topology outside the lens. The lens size also determines the precision with which node similarity can be discerned in the lens interior. If similarity is central to the data analysis, a large lens with higher precision can be used. For quick glances on similarity, a smaller lens with lower precision may suffice.

To adapt the lens to different analytical interests, a dedicated user interface is provided. It allows users to specify the node attributes to be taken into account for the similarity calculation. Changing the attributes triggers a recalculation of the similarity matrix and a corresponding update of the node layout within the lens. The similarity threshold can also be set from the user interface. The threshold controls how many nodes will eventually be affected by the layout adaptation. Currently, the similarity threshold can be set via a slider component. Finally, the mode of the radial guides as well as the additional edge-clutter reduction effect can be controlled within the user interface. For a more direct adjustment of all important parameters, it would be desirable to consider dedicated on-lens controls [HTE11; KRD16].

In summary, the similarity lens is a simple yet effective tool to support on-the-fly visual exploration of similarities in multivariate graphs through dynamic layout adaptation. Next, we illustrate the utility of the lens for a real-world dataset.



**Figure 2:** Applying the similarity lens to a graph of soccer players. (a) Node-link diagram showing a part of the graph topology. (b) The activated similarity lens places similar nodes within the lens. (c) Radial guides and edge clutter reduction enhance the similarity exploration. (Note that some labels use a leader line to connect to their nodes. This is the case, for instance, for Corentin Tolisso near the lens center.)

#### 4. Use Case

Assume we are soccer enthusiasts and study a multivariate graph of soccer players from the CL season 2017/18. Each node of the graph represents a player with multivariate attributes capturing the players' offensive and defensive properties (e.g., minutes played, ball possession, shots on goal, scored goals). Edges exist between players that have played in the same club. The number of clubs in which two players have played is captured as the edge weight. Overall, the graph has 95 nodes, 1046 edges, and 39 quantitative node attributes. The zoomed-in node-link diagram in Figure 2a shows a part of the graph topology. Node degree is visualized by node size and shades of blue. Edge weight is encoded in the link width. Player names are placed with a conflict-reducing labeling algorithm.

As we explore and zoom in the graph, we find the player Thiago Alcántara. Figure 2a shows that he is comparatively strongly connected in the graph. But it is not clear who is similar to him. Here, we are particularly interested in his goal-getter qualities and select the number of goals, total shots, on-target shots, and minutes played as the relevant attributes for the similarity calculation.

In Figure 2b, we activated the similarity lens and placed it on Thiago. Players that do not meet the similarity threshold of 85% are pushed out of the lens. Players who resemble Thiago are smoothly pulled into the lens and are colored in shades of green to indicate their similarity. As can be seen, seven similar players are brought to the lens. Thomas Müller and Dimitri Oberlin near the lens border are the least similar ones (with respect to the set similarity threshold). But we are not quite sure about who the most similar player is. Is it Willian or Corentin Tolisso?

For a more detailed look at the situation, we activated the visual enhancements in Figure 2c. The radial guides improve the interpretation of the similarity. We can now easier see that Tolisso is slightly closer to Thiago and hence can conclude that they are the most similar players with respect to their goal-getter qualities. Moreover, the edge-clutter reduction improves the visibility of relevant edges in the lens and makes it easier to investigate the connectivity of the similar players. The supplementary video offers further illustration.

#### 5. Conclusion

We proposed the similarity lens as a novel focus+context approach that addresses the task of exploring attribute-based similarity in multivariate graphs. The core idea is to dynamically create a layout where topological features and multivariate attribute characteristics are smoothly intertwined. That is, nodes are positioned inside the lens with respect to their multivariate similarity, while a topological layout is preserved outside the lens. Additional visual enhancements further support the similarity exploration. Interested readers can try out a prototype at: <https://t1p.de/sim-lens>.

As for all lens techniques, the similarity lens aims for a compromise between potentially conflicting data exploration needs (understand graph topology vs. understand multivariate attributes). With its lightweight transient layout adaptation, it provides quick access to relevant information (node similarity) without disturbing the analysis flow too much. While the lens can hint at interesting findings, a detailed analysis of node similarities and multivariate attributes would still require dedicated visualization designs. Yet, our similarity lens can make it easier to spot parts of the data for which a switch to different visual representations could be worthwhile.

In the future, it would be interesting to further investigate the similarity representation inside the lens. As is, our lens pursues a node-of-interest strategy where similarity is considered with respect to a focus node. Alternatively, one could consider a global strategy where nodes under the lens are re-positioned using dimensionality reduction methods such as MDS, t-SNE, or UMAP. Another possible avenue for future work is to enhance the presentation of the underlying data attributes within the lens. While in-lens nodes currently represent similarity by their distance to the lens center (and their color), it is not clear how individual attributes contribute to the similarity. Here it could make sense to dynamically embed additional information, for example, by transforming the simple dots into multivariate glyphs representing the attributes used for the similarity calculation. Finally, it would be interesting to compare plain topology-driven layouts, attribute-driven layouts, and our dynamic lens-driven hybrid layout in a user evaluation.

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